

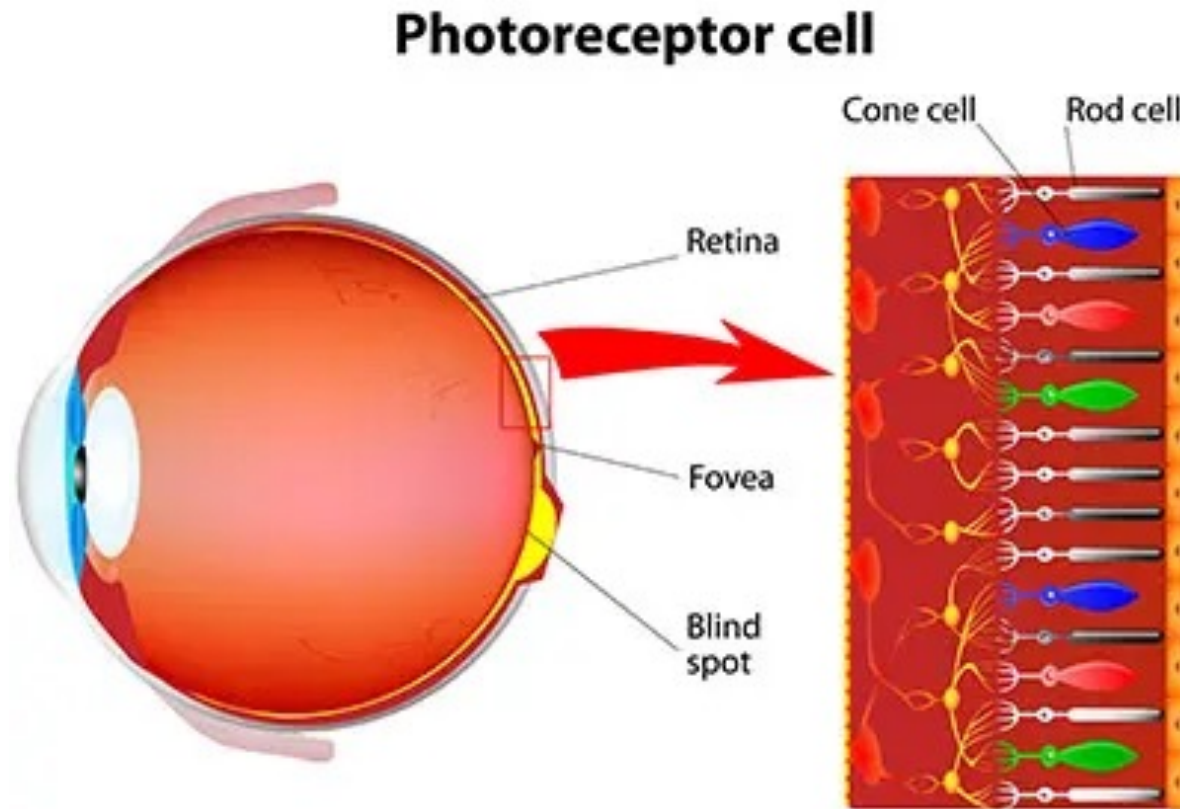
3 - Seeing Colour & Colour Spaces

Prof Peter YK Cheung

Dyson School of Design Engineering

URL: www.ee.ic.ac.uk/pcheung/teaching/DE4_DVS/
E-mail: p.cheung@imperial.ac.uk

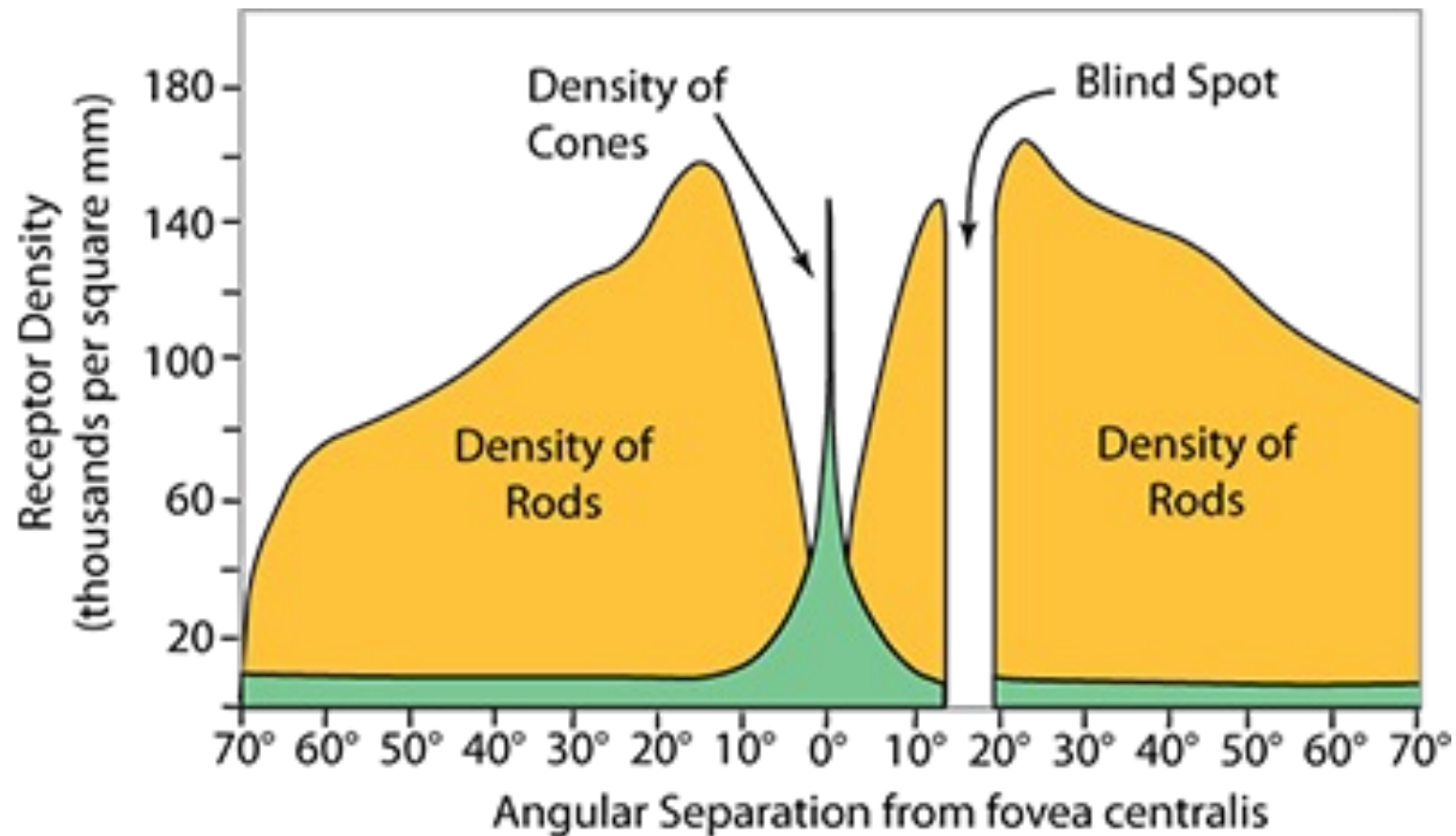
Photoreceptor cells in Retina



- ◆ Retina have three types of cones that are primarily responsible for seeing red, green and blue colours

Source: American Academy of Ophthalmology

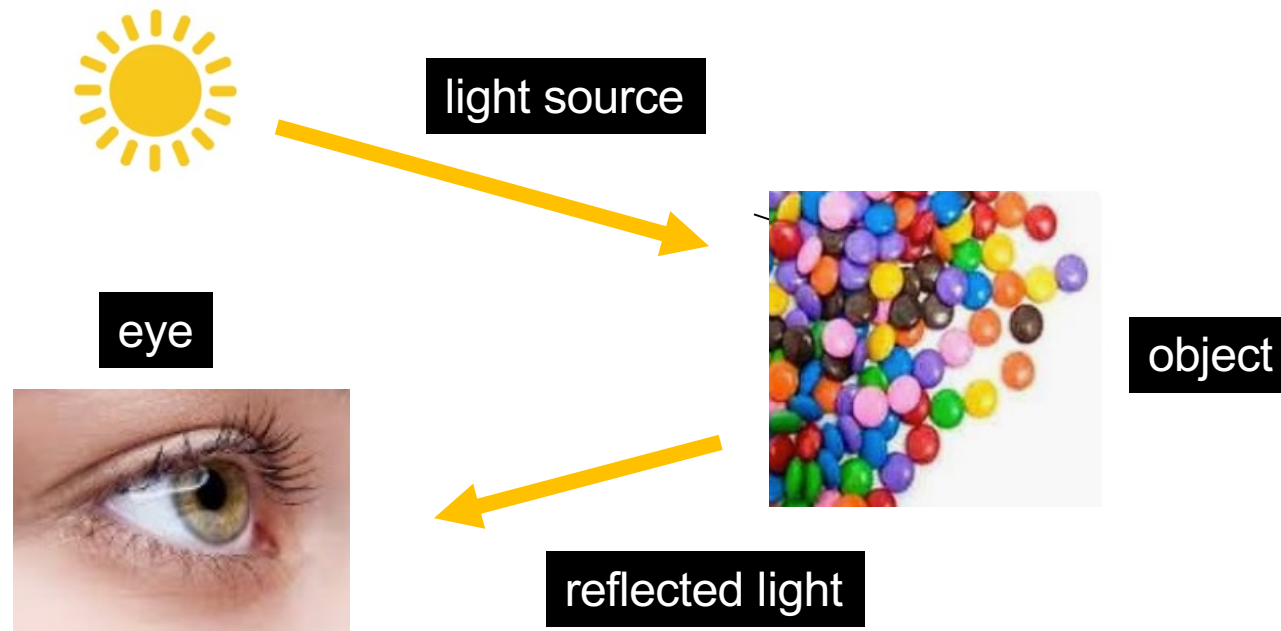
Densities of rods and cones



- ◆ Concentration of cones at very high density only in the fovea region, around $\pm 6^\circ$ around the centre of vision.
- ◆ Concentration of rod is spread out.

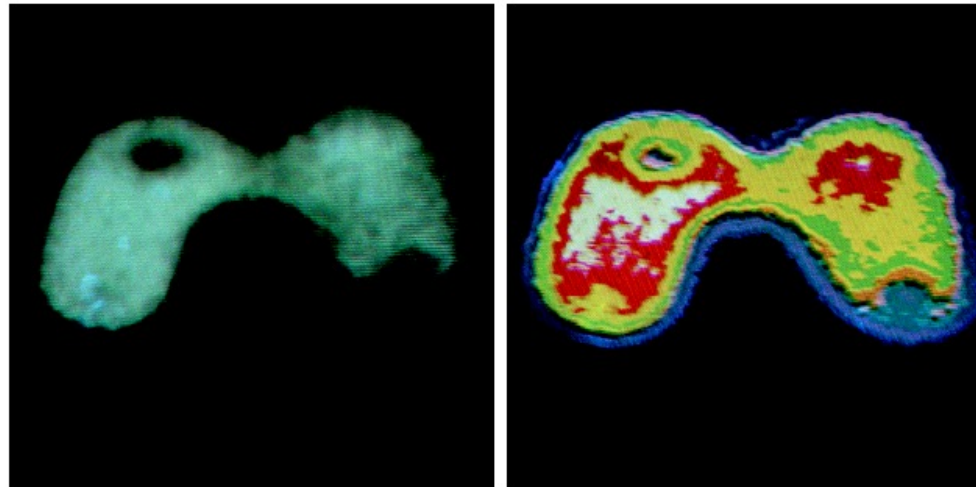
How we see colour of objects?

- ◆ The colour that human perceive in an object = the light **reflected** from the object



Why use Colour in Visual Systems

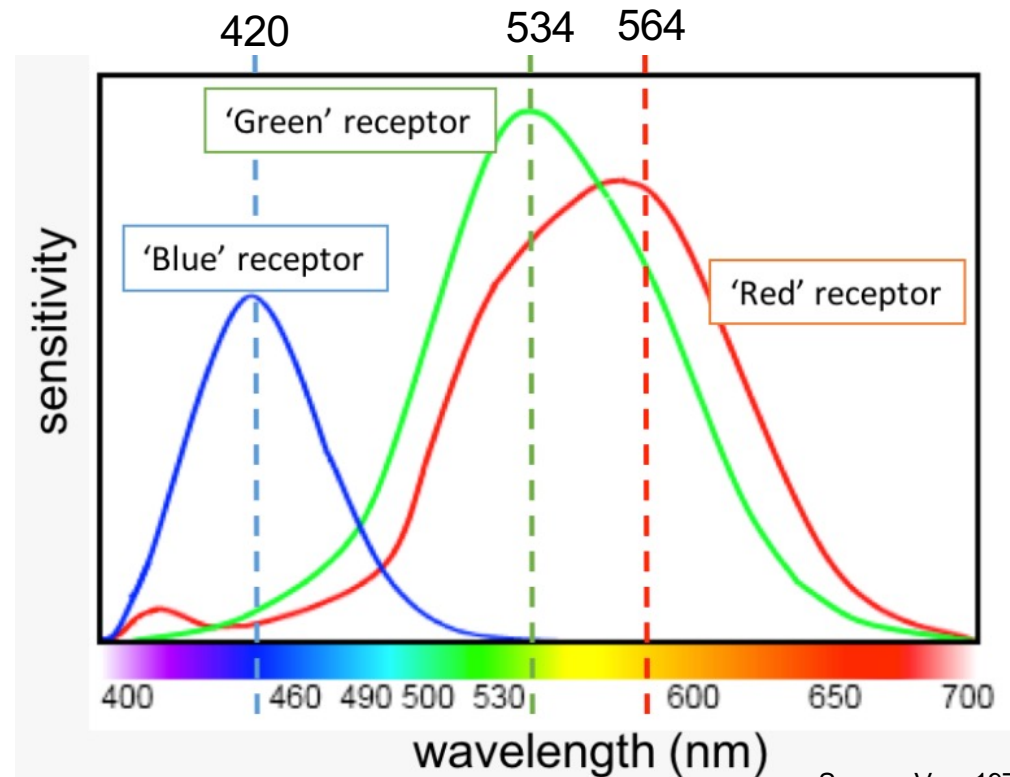
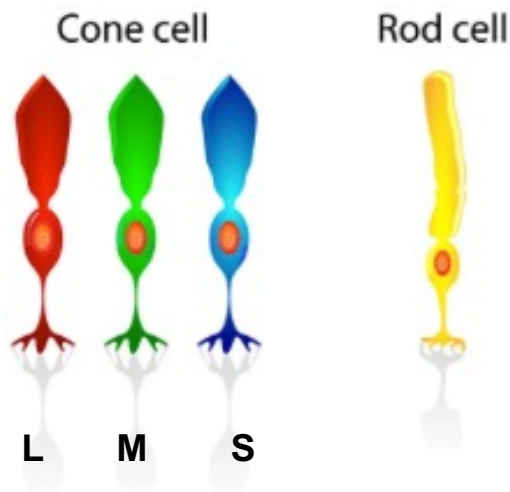
- ◆ Why use color in the design of visual systems?
 - Color is a powerful descriptor
 - Object identification and extraction
 - eg. Face detection using skin colors
 - Humans can discern thousands of color shades and intensities
 - c.f. Human discern only two dozen shades of grays
- ◆ We even use false colour to characterize greyscale images (e.g. in medicine)



Trichromatic Theory

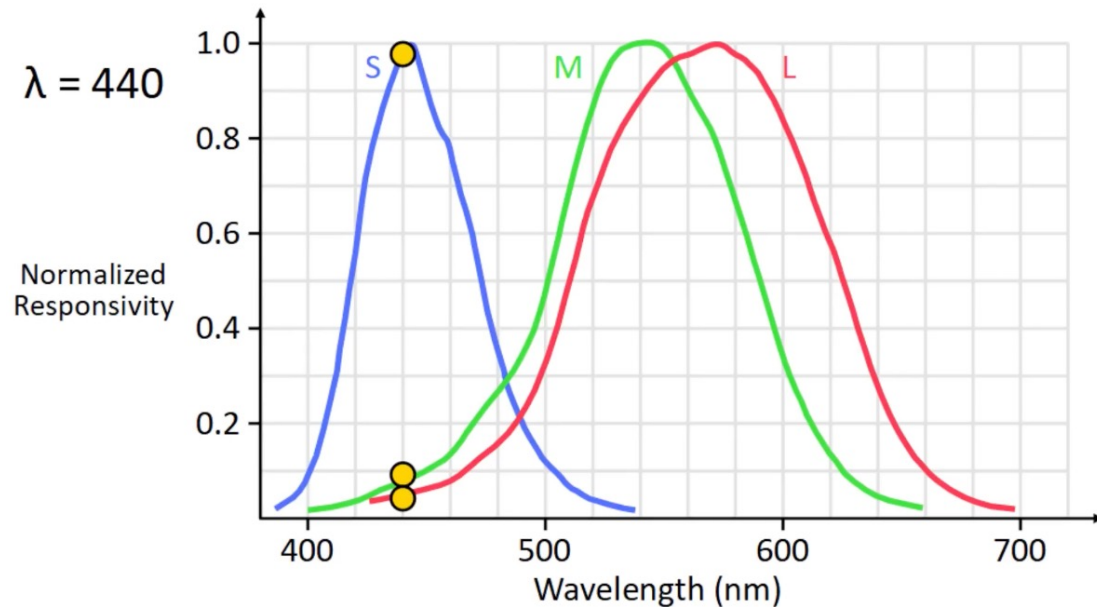
◆ Trichromatic theory (Young and Helmholtz)

- Three types of cones in retina
- Each type has photopigments sensitive to three different wavelengths
- Red (long), Green (medium), Blue (short)



Source: Vos, 1978

How does our brains "see" blue?



0.05

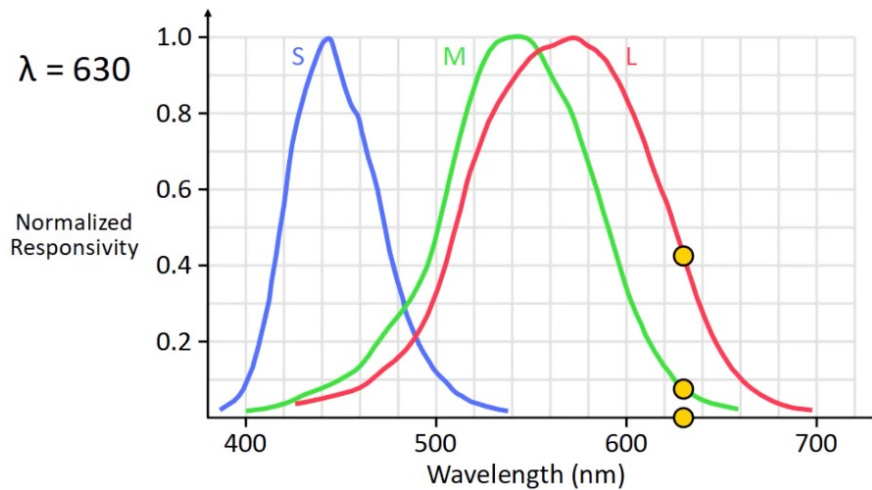
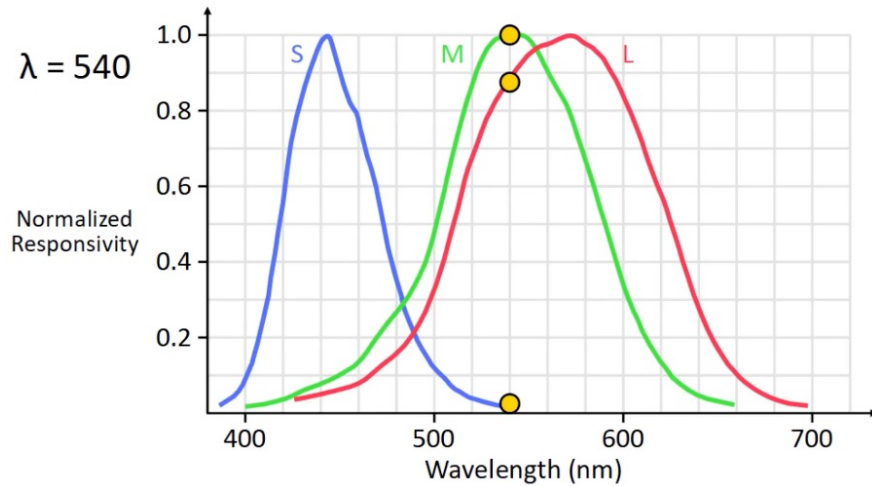
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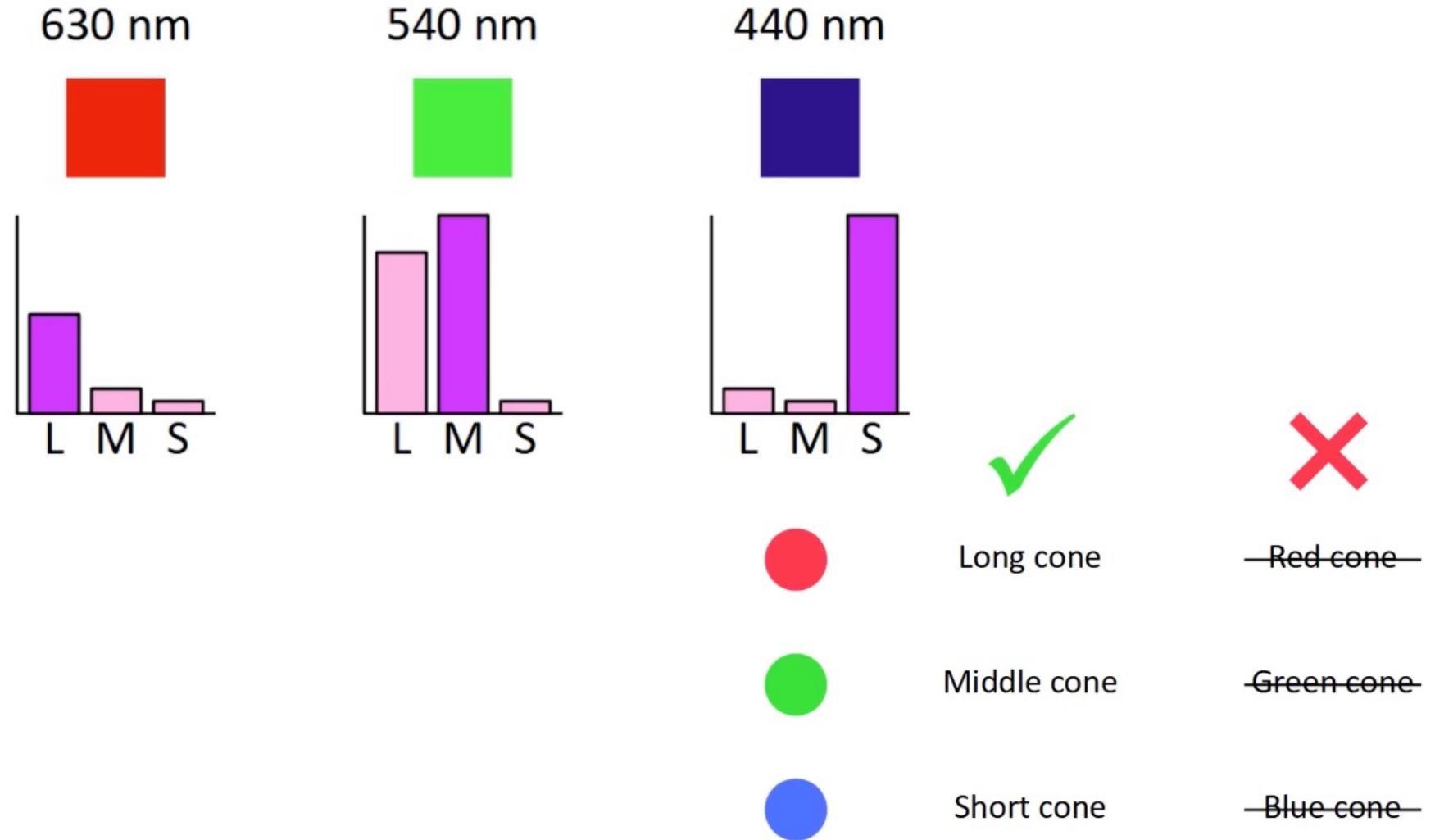


- ◆ Blue light at 440nm wavelength will strongly stimulate the S cone, but not the M and L cones.
- ◆ Our brain interprets this as blue colour.

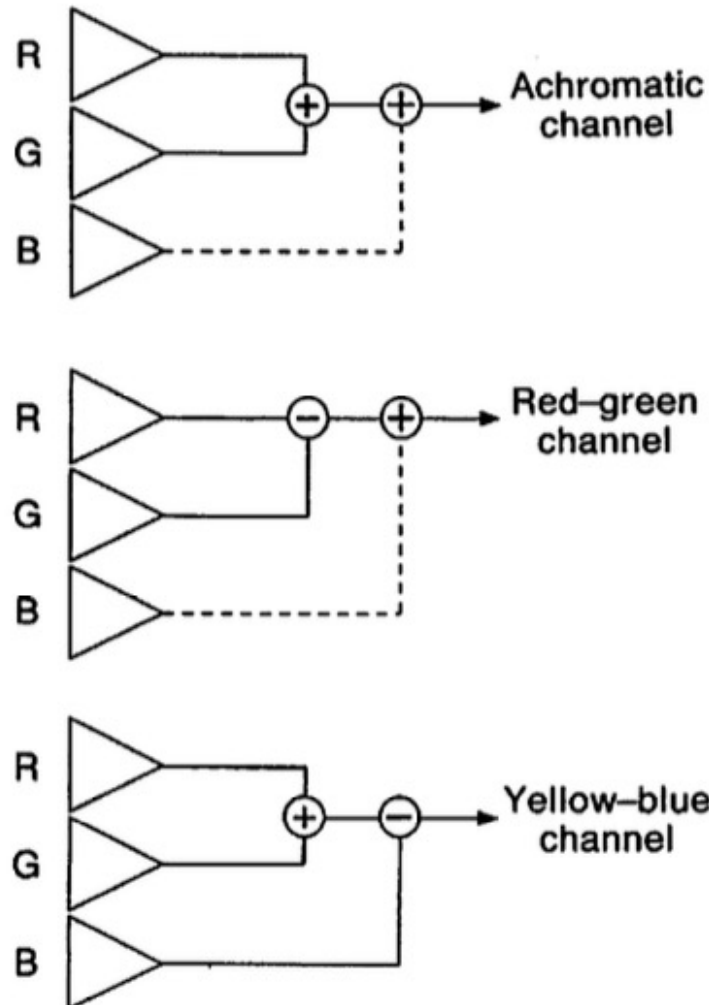
"Seeing" green and red colours



Don't call them RGB, but LMS!



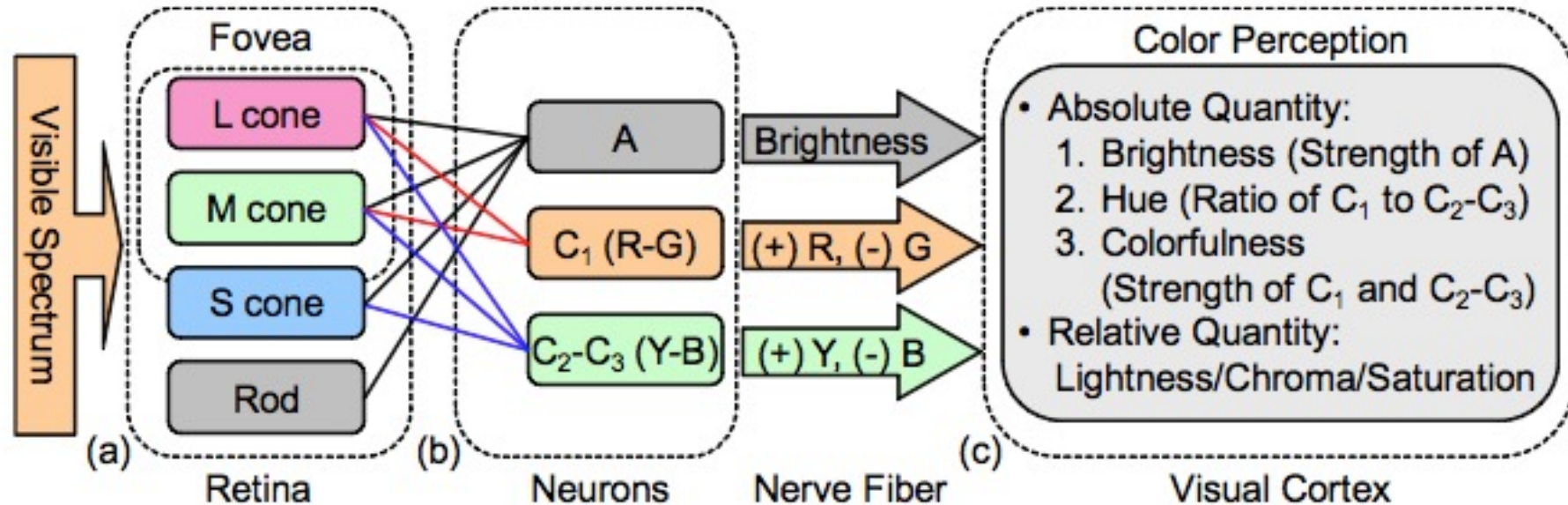
Opponent Process Theory (Herring)



- ◆ Three types of mechanisms combine cones signals in both additive and inhibitive ways.
- ◆ The achromatic channel is sensitive to all three cones and detects only the luminance information (i.e. black vs white)
- ◆ The Red-Green channel compares the difference in red and green cone signals (i.e. one inhibits the other)
- ◆ The Yellow-Blue channel compares the difference between blue cone signals with the sum of red and green signals.
- ◆ This theory explains some of the colour perception experiments in human visions

Source: Tovee p45-46

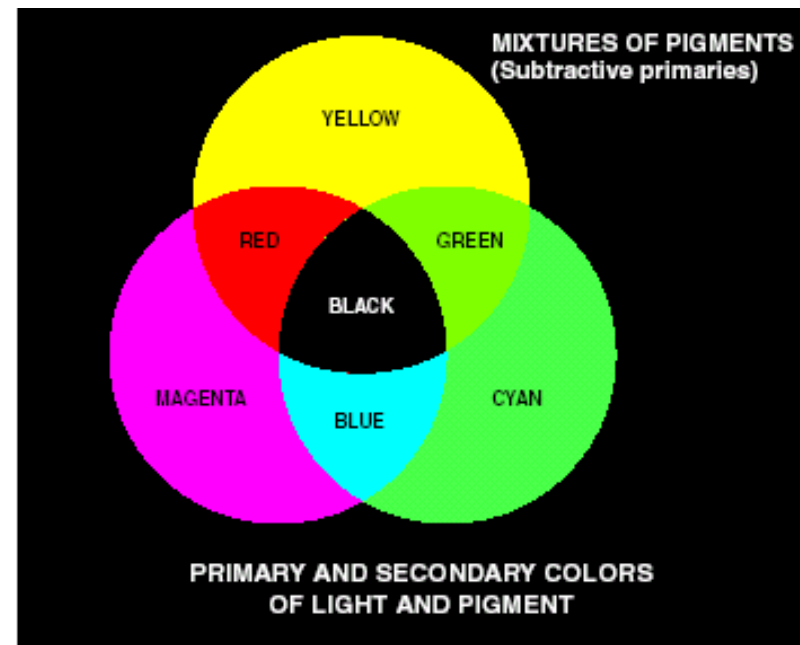
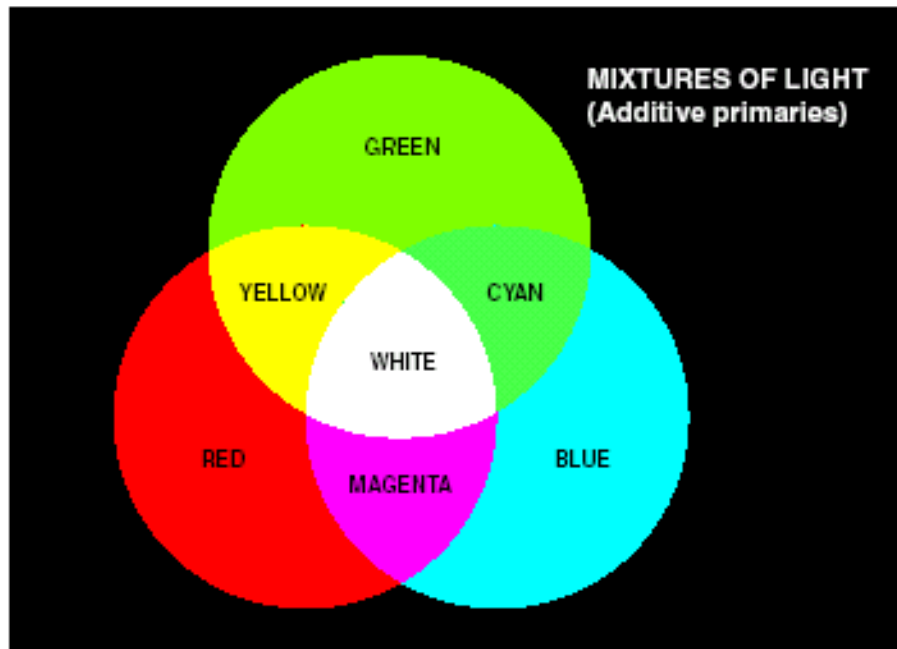
Opponent Process Theory of Colour Perception



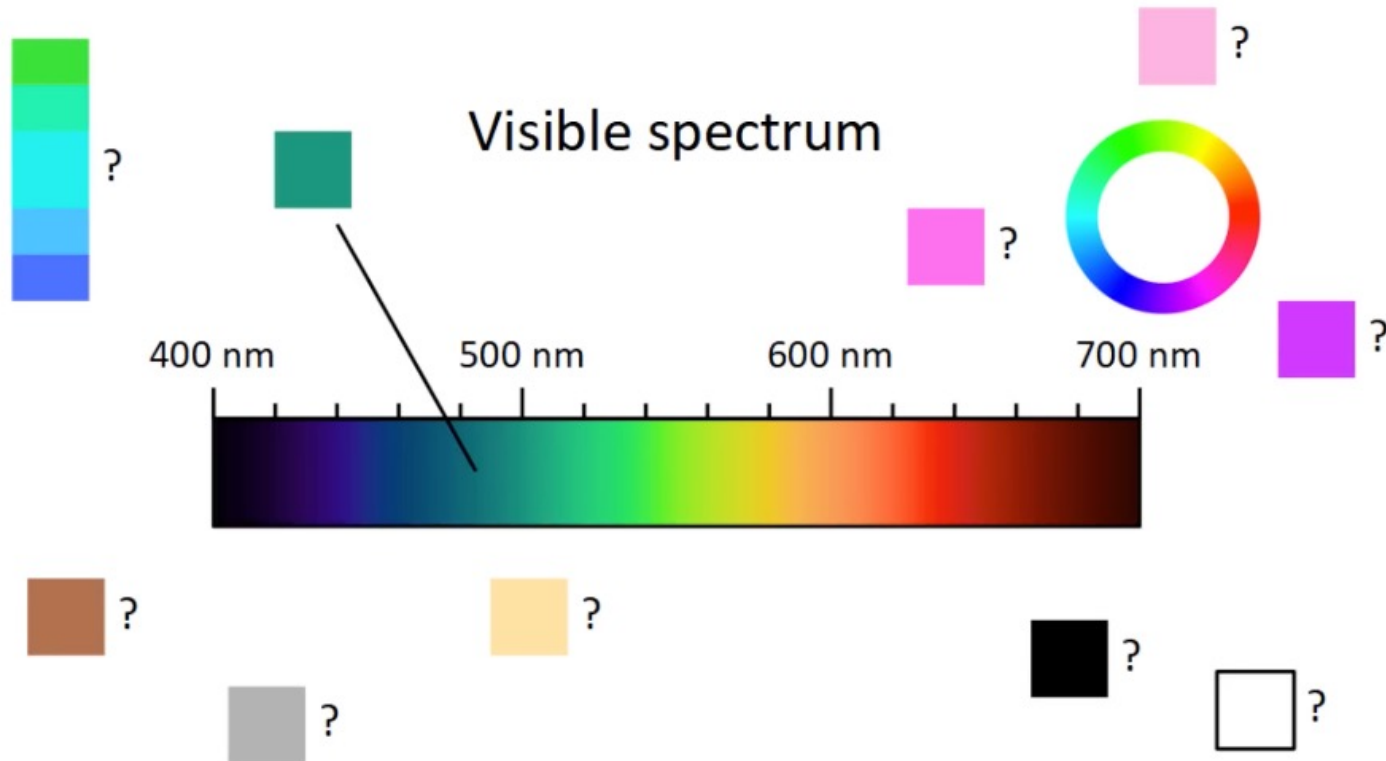
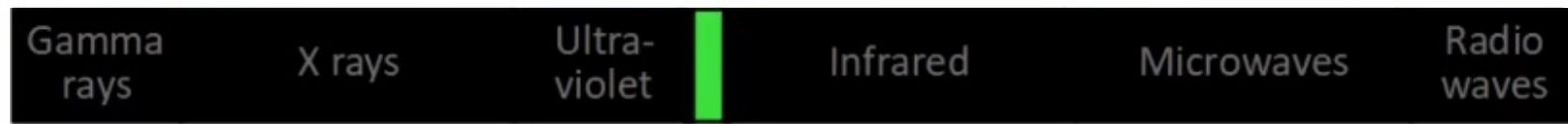
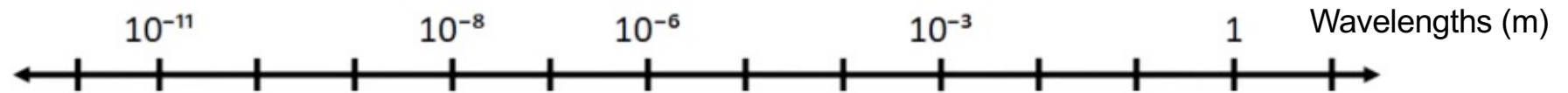
- ◆ Here is another view of how the opponent process theory explains our colour perception mechanism.

Primary and secondary colors

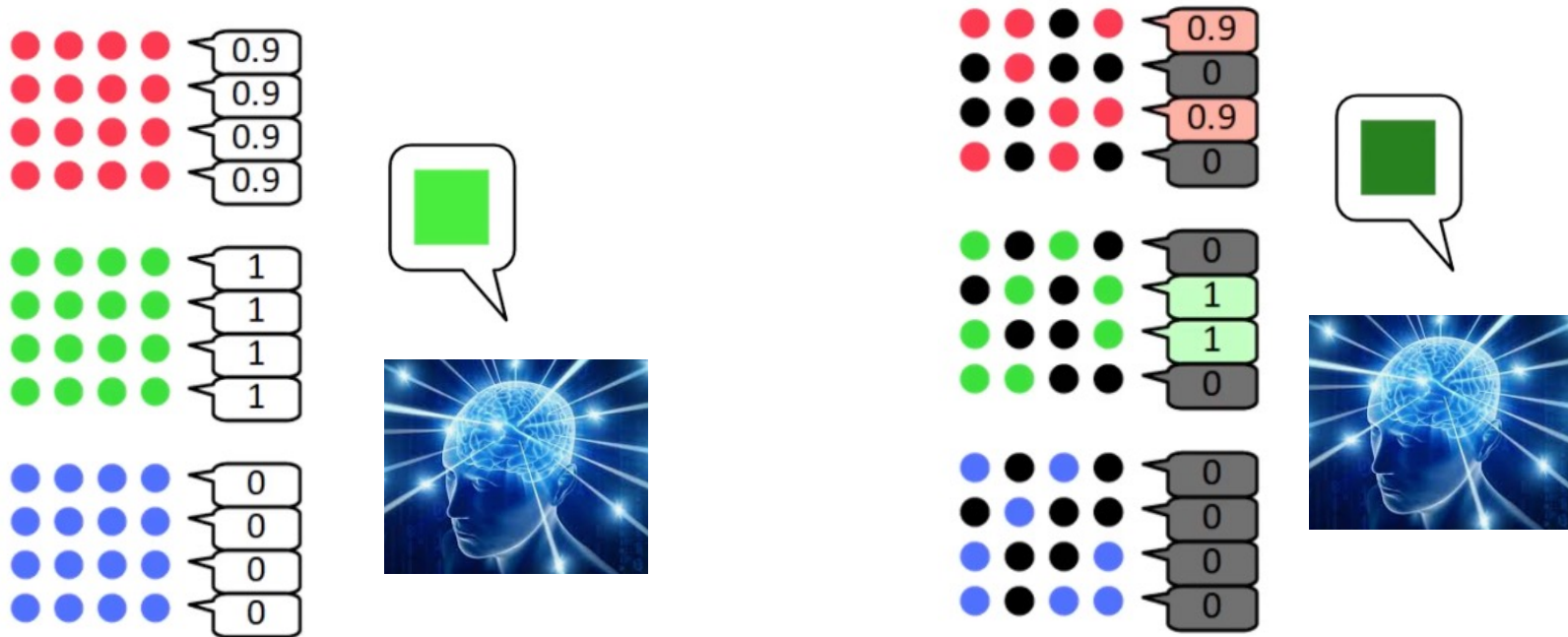
- ◆ In 1931, **CIE**(International Commission on Illumination) defines specific wavelength values to the **primary colours**
 - B = 435.8 nm, G = 546.1 nm, R = 700 nm
 - However, we know that no single color may be called red, green, or blue
- ◆ **Secondary colours**: G+B=**C**yan, R+G=**Y**ellow, R+B=**M**agenta



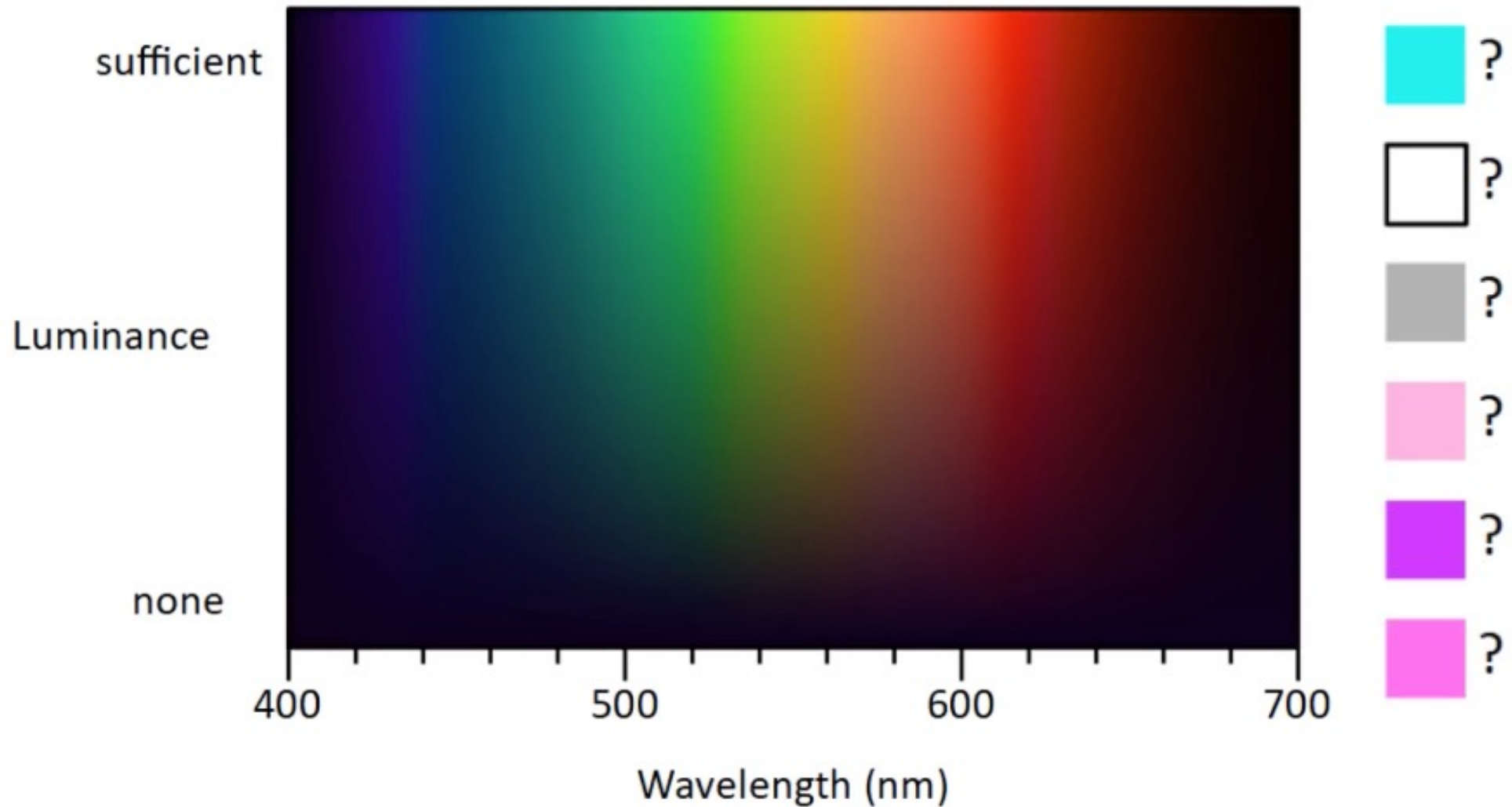
Limitation of the visible spectrum



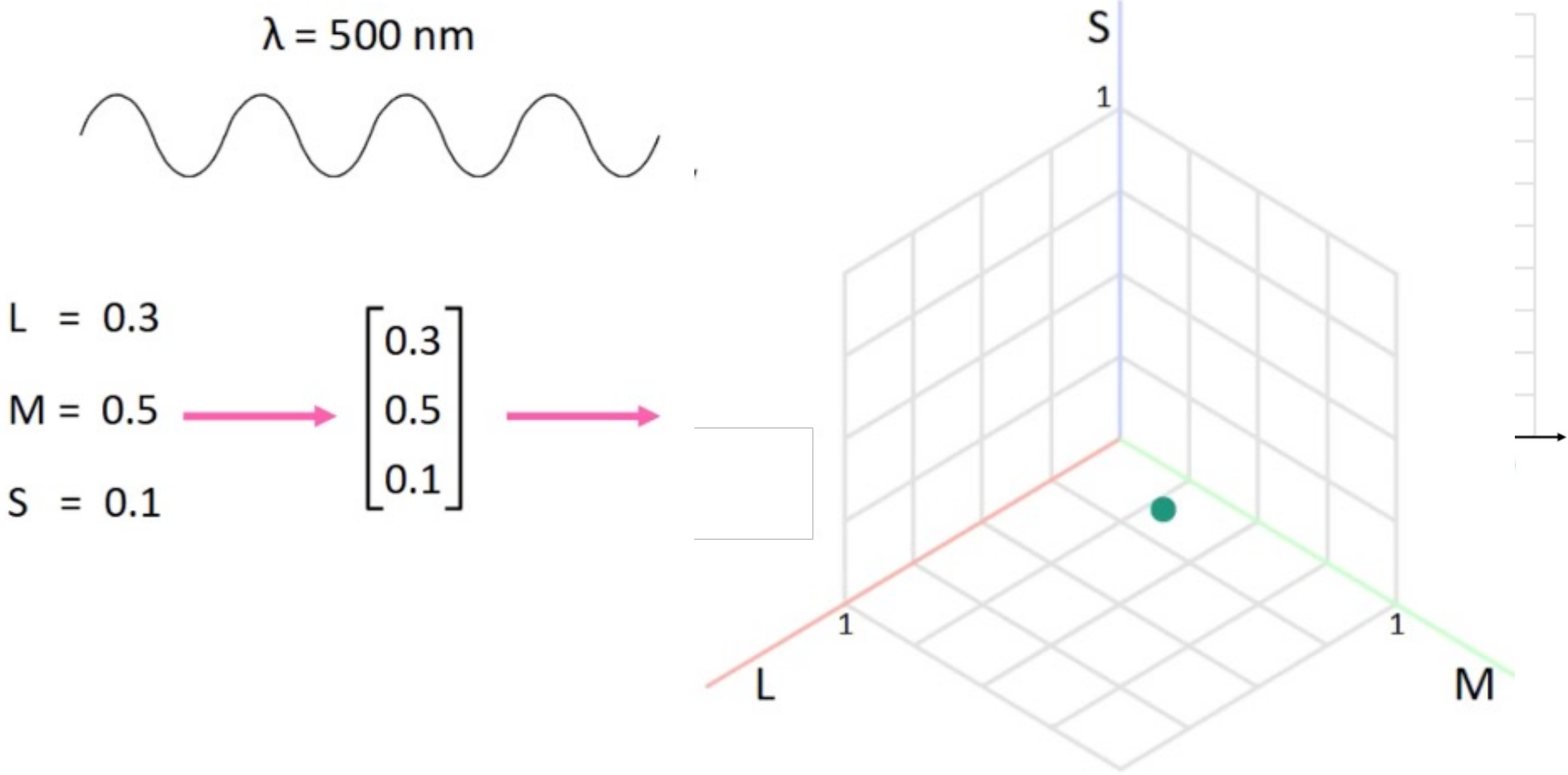
The idea of luminance and chrominance



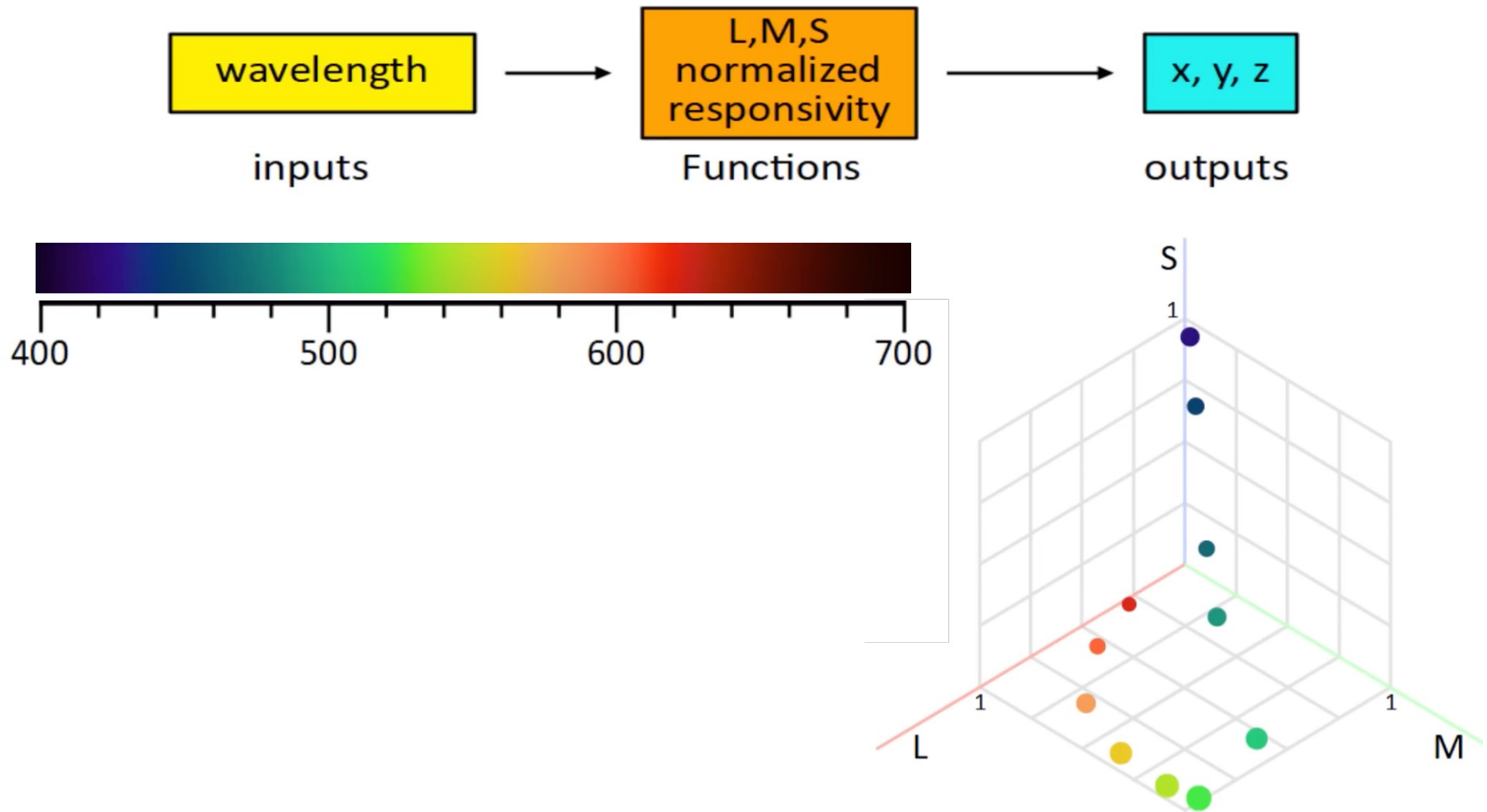
Luminance vs Wavelength is not sufficient



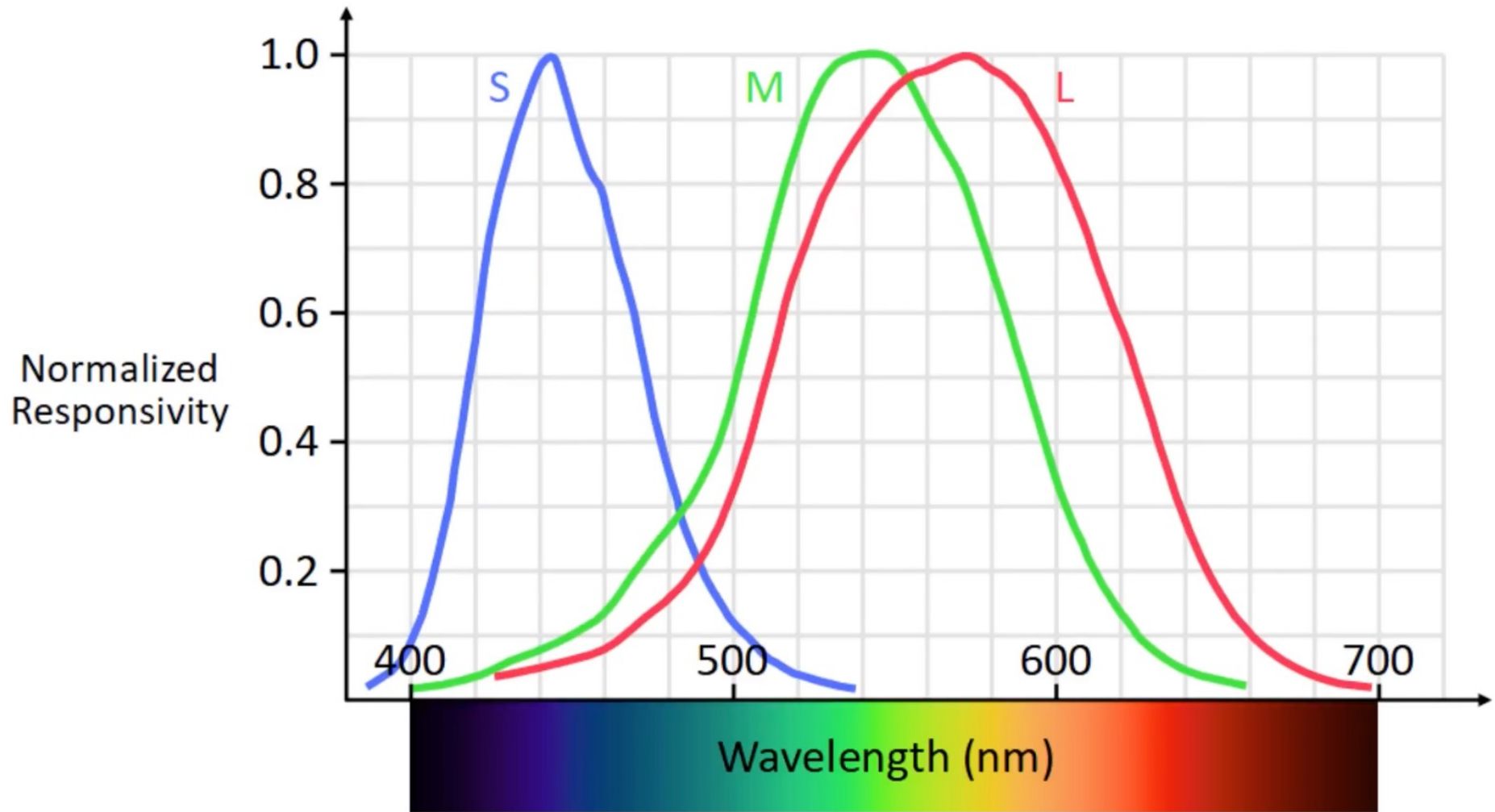
LMS Colour Space



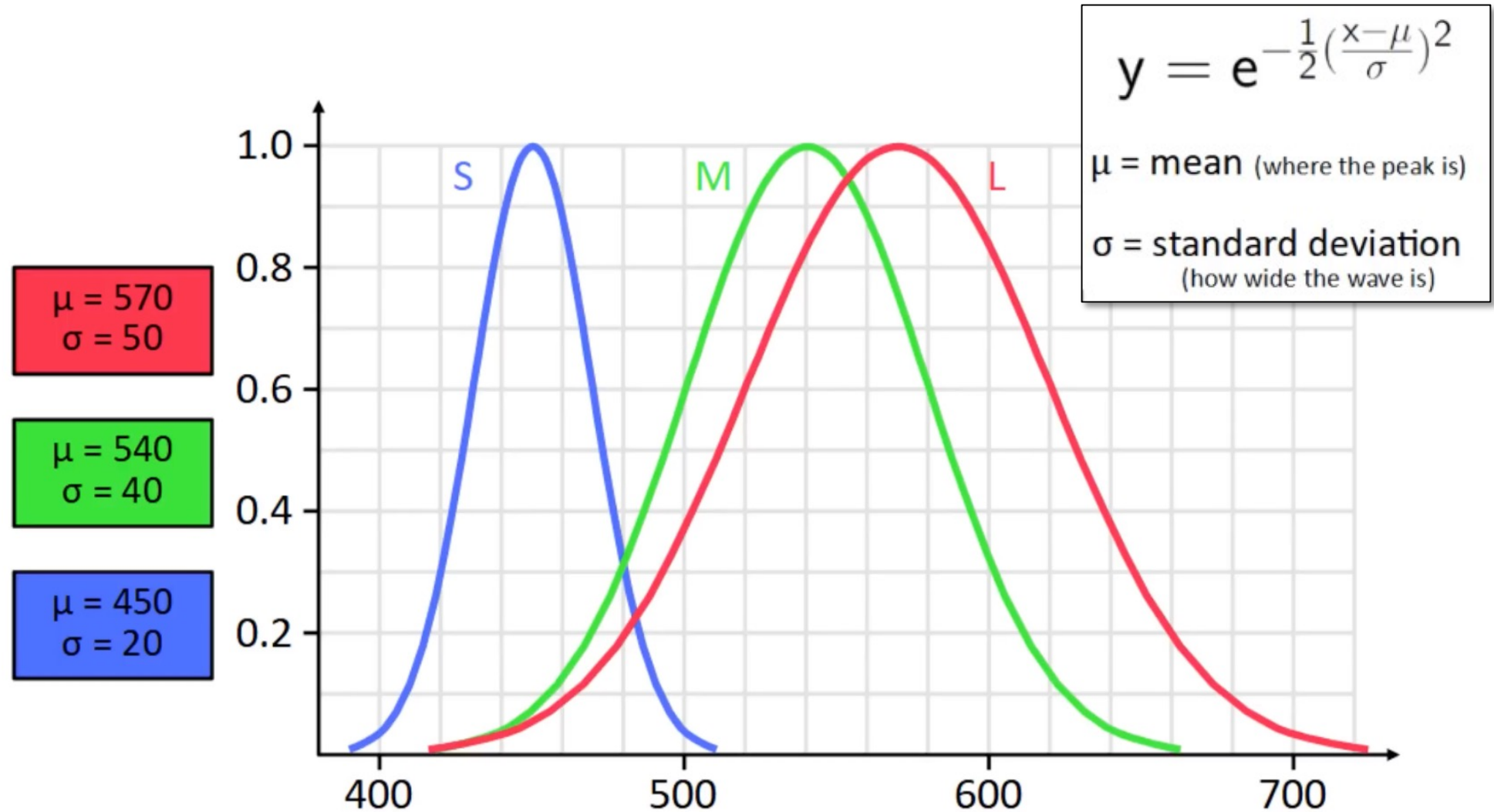
Mapping wavelengths of colour to 3D space



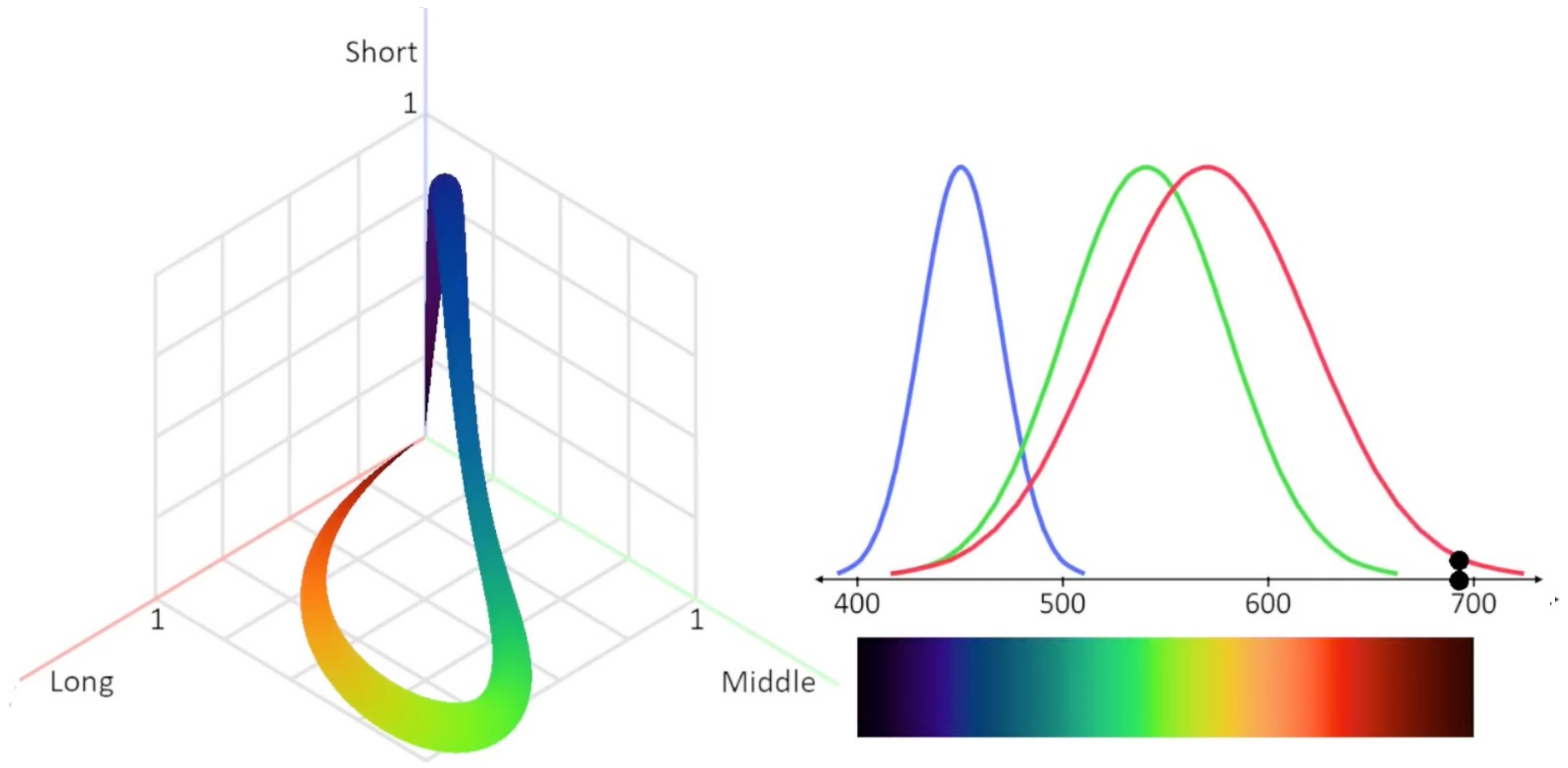
Normalised Cone Responses



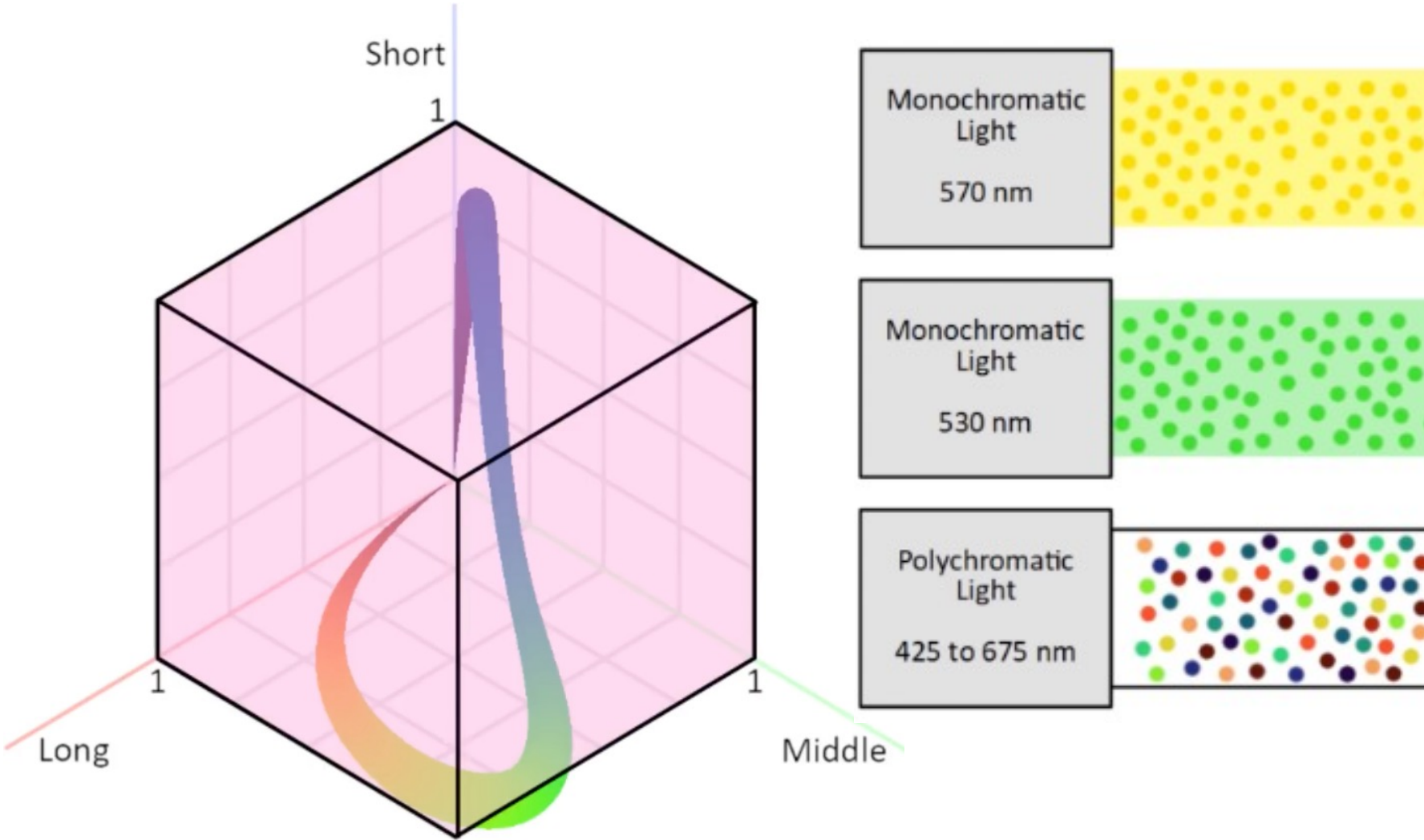
Gaussian Approximation



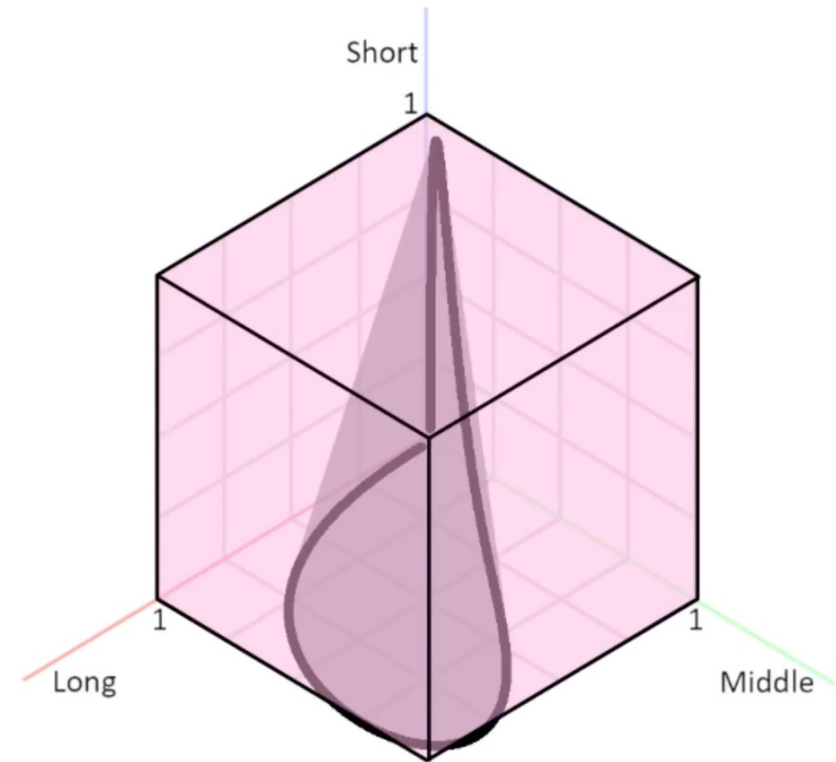
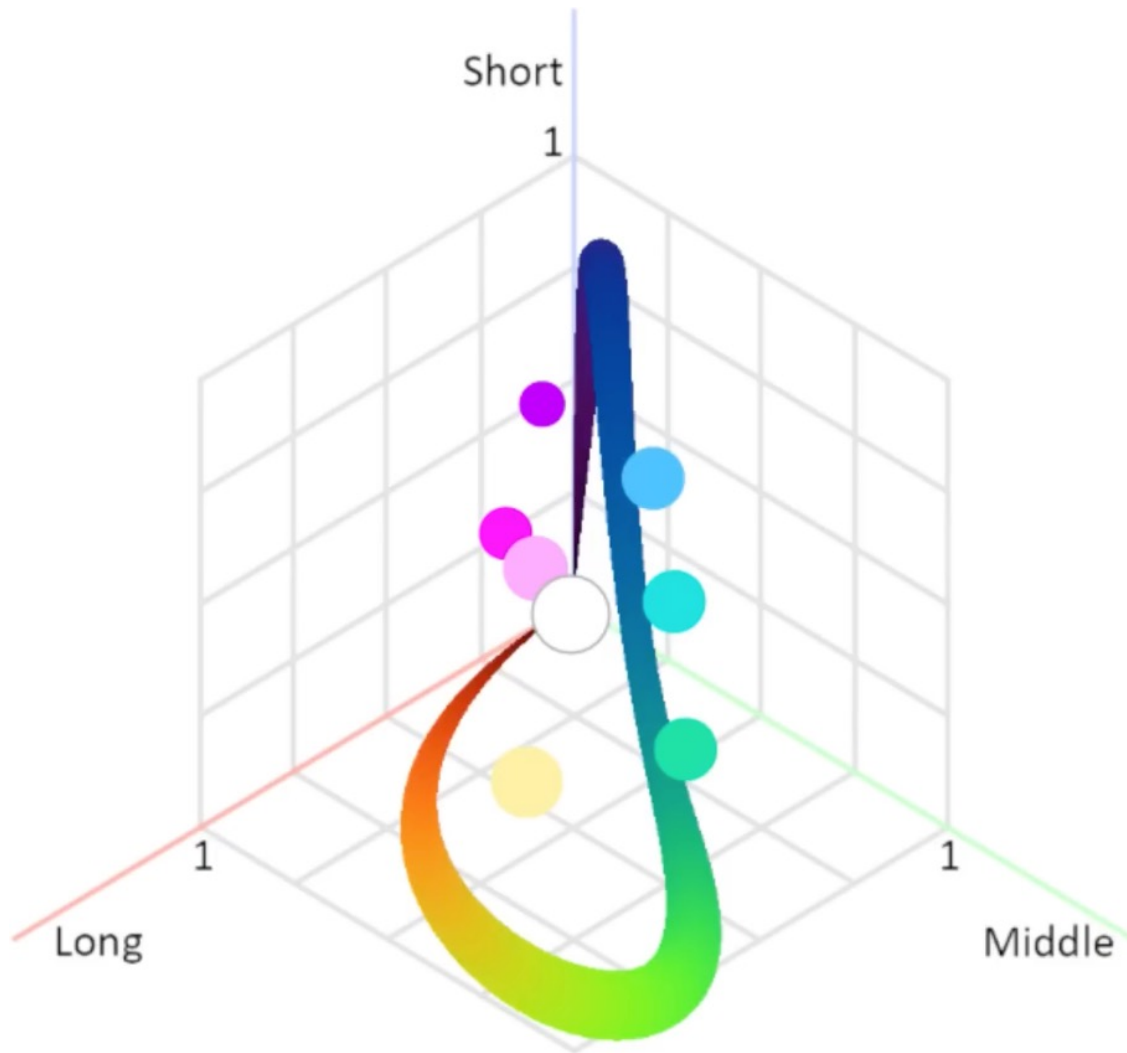
Visible Spectrum mapped onto LMS space



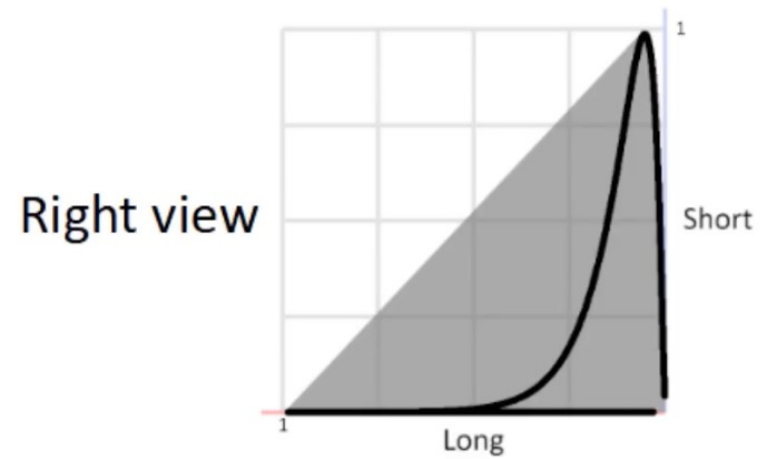
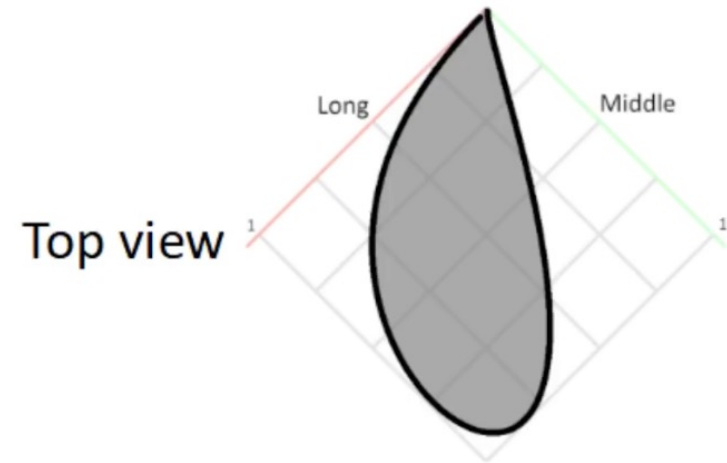
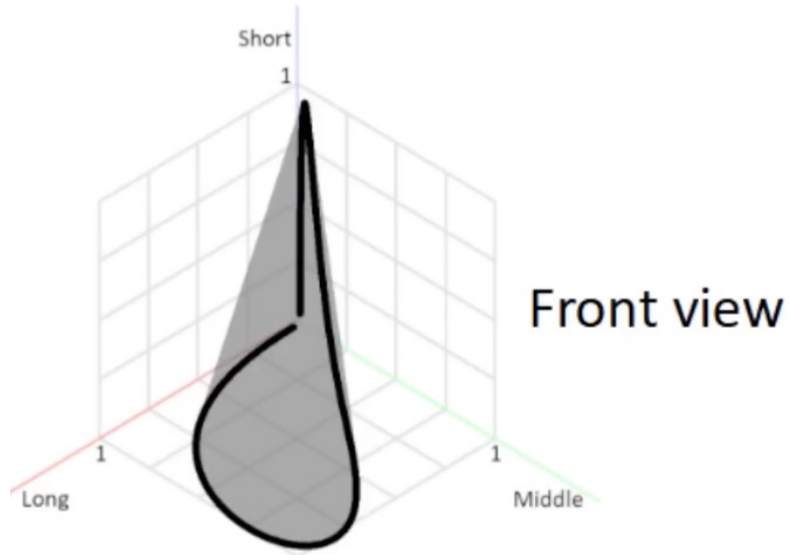
LMS cube can have many more colours



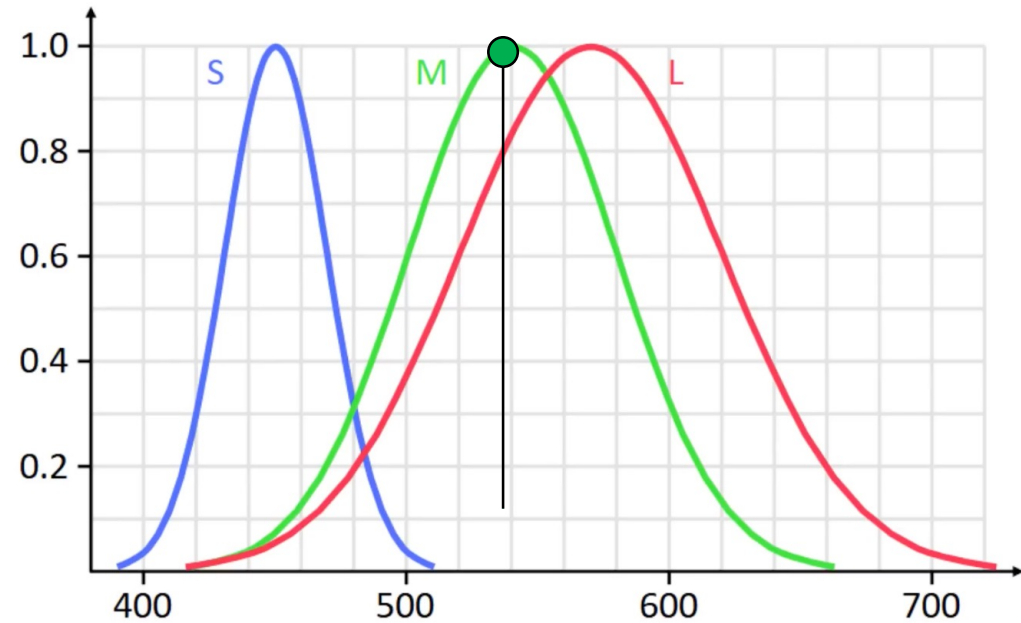
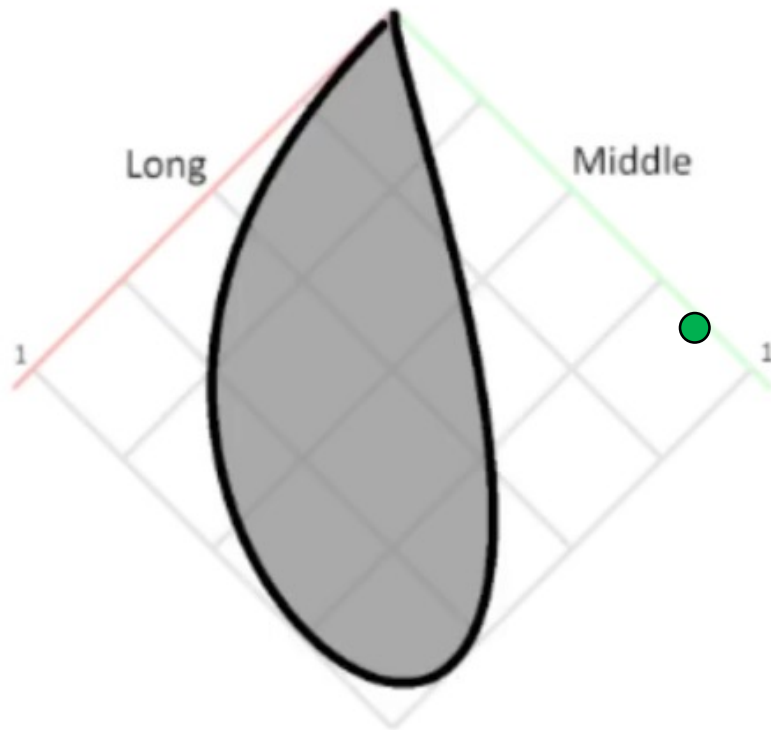
More colours in the 3D Colour Space



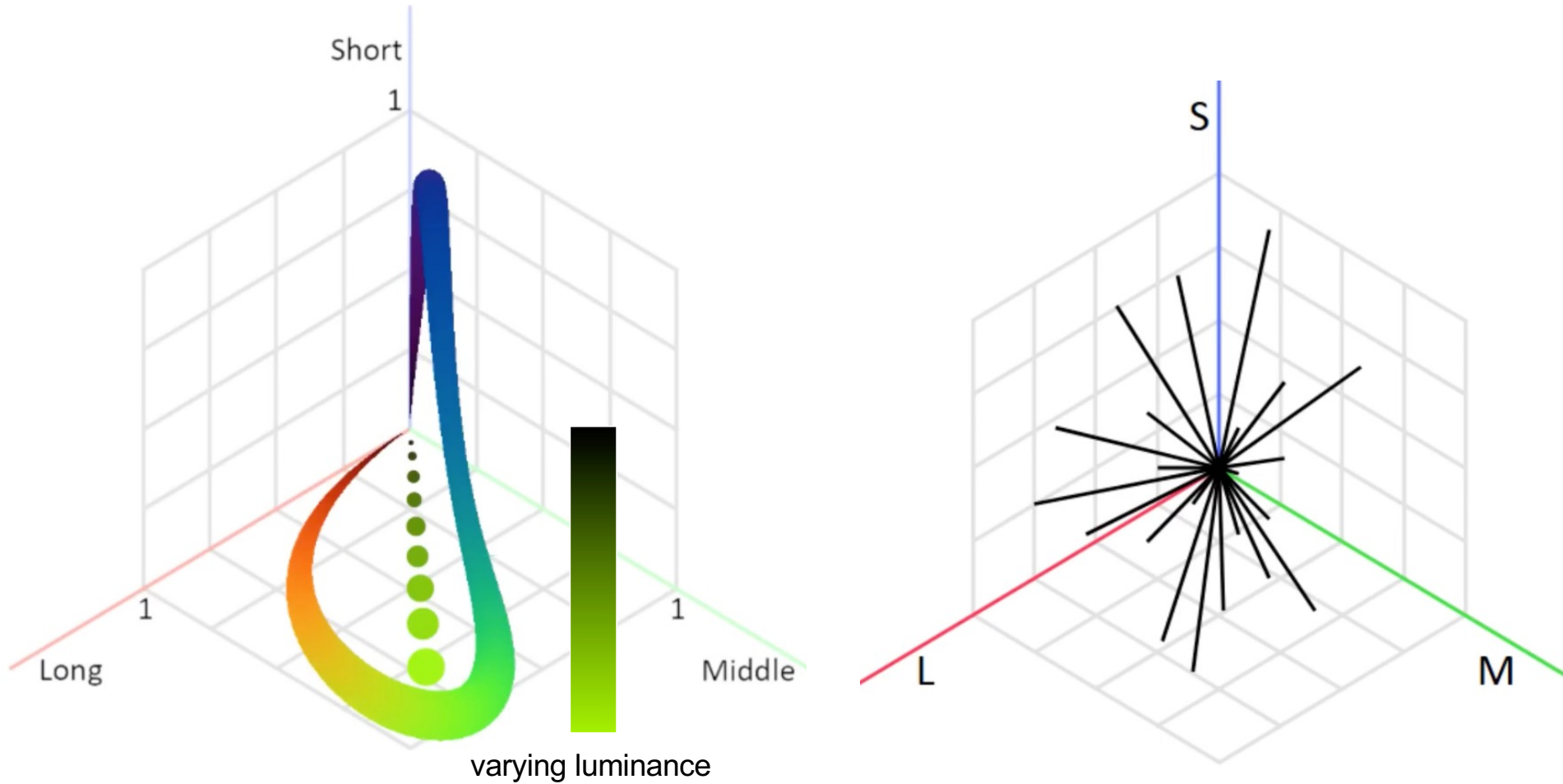
The Visible Gamut



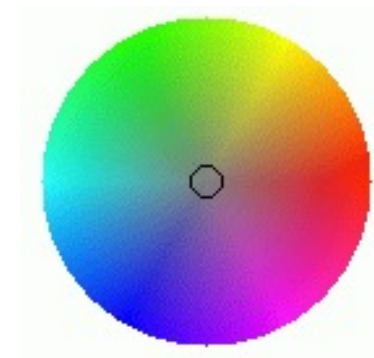
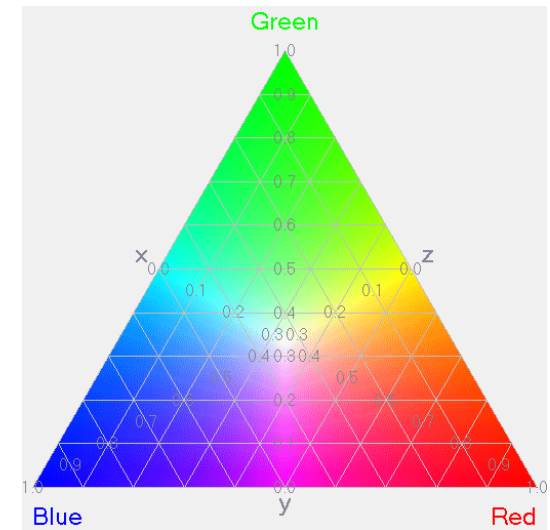
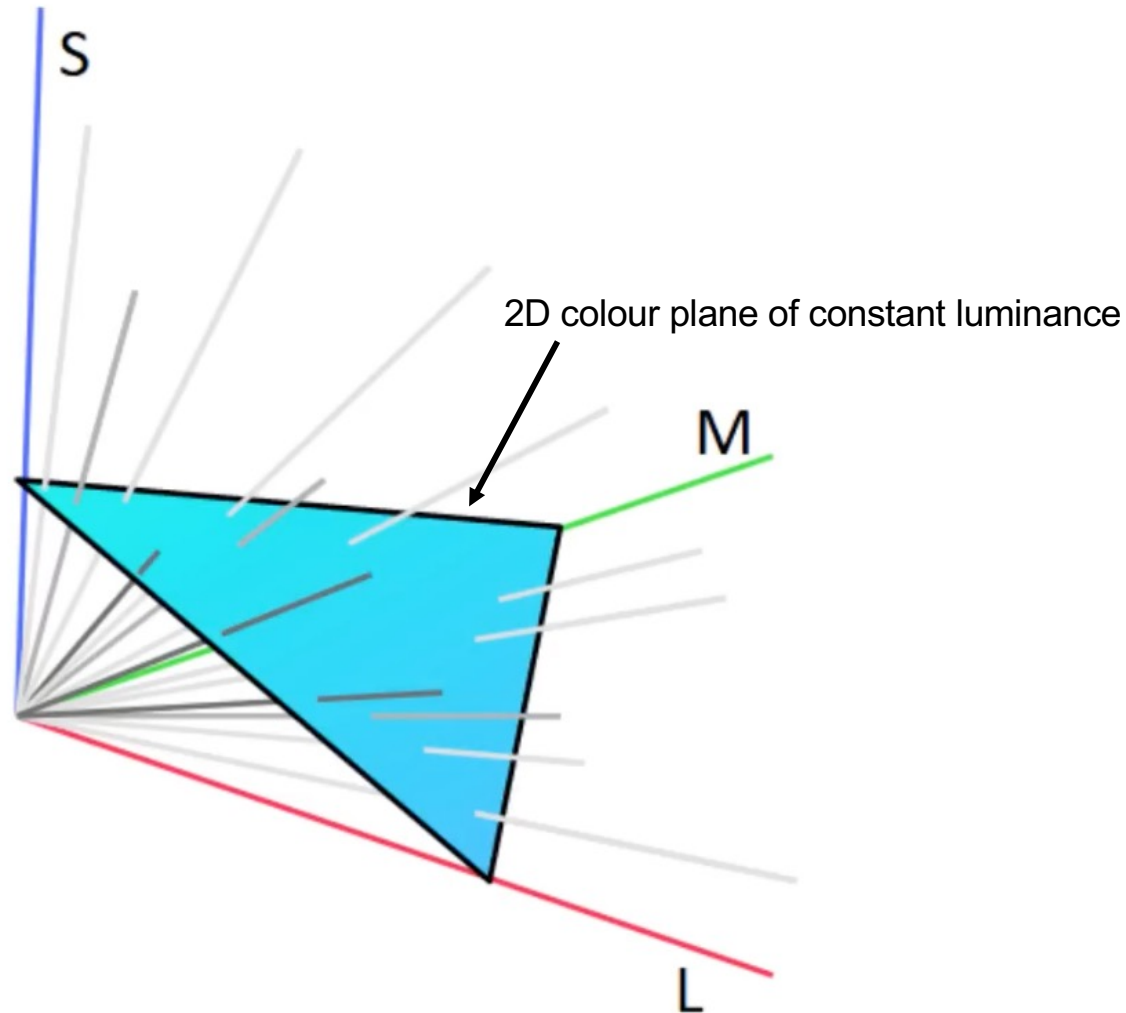
Why are some colour impossible in 3D Space?



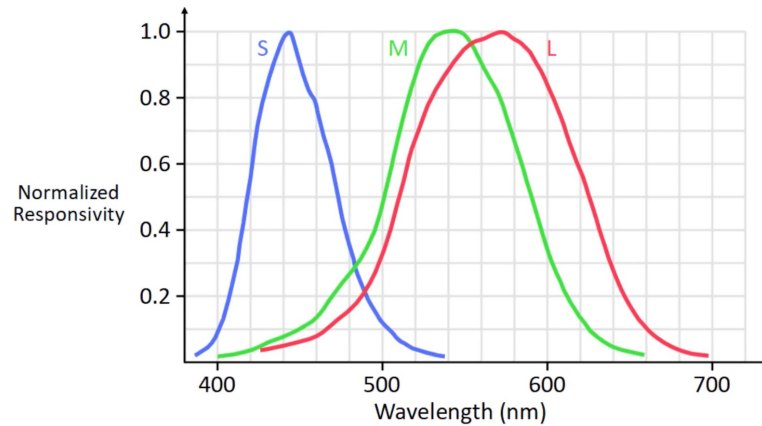
Constant Colour (Chromaticity)



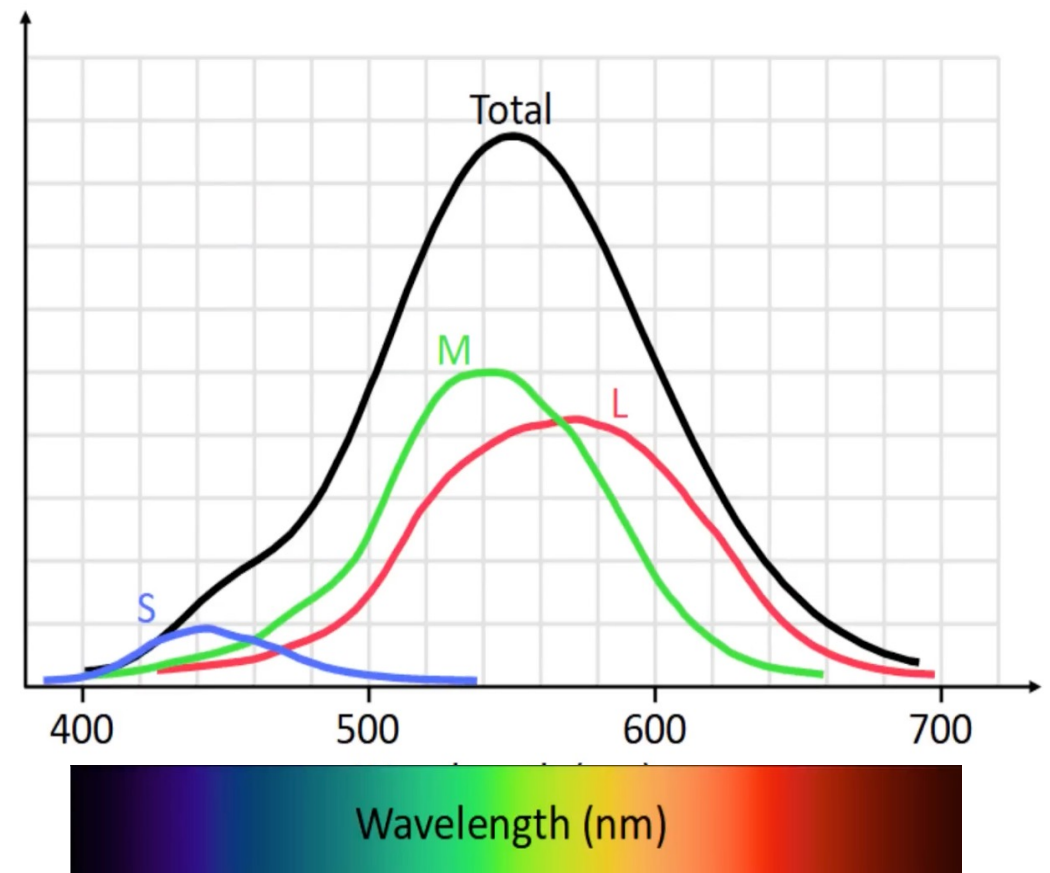
Plane of Constant luminance



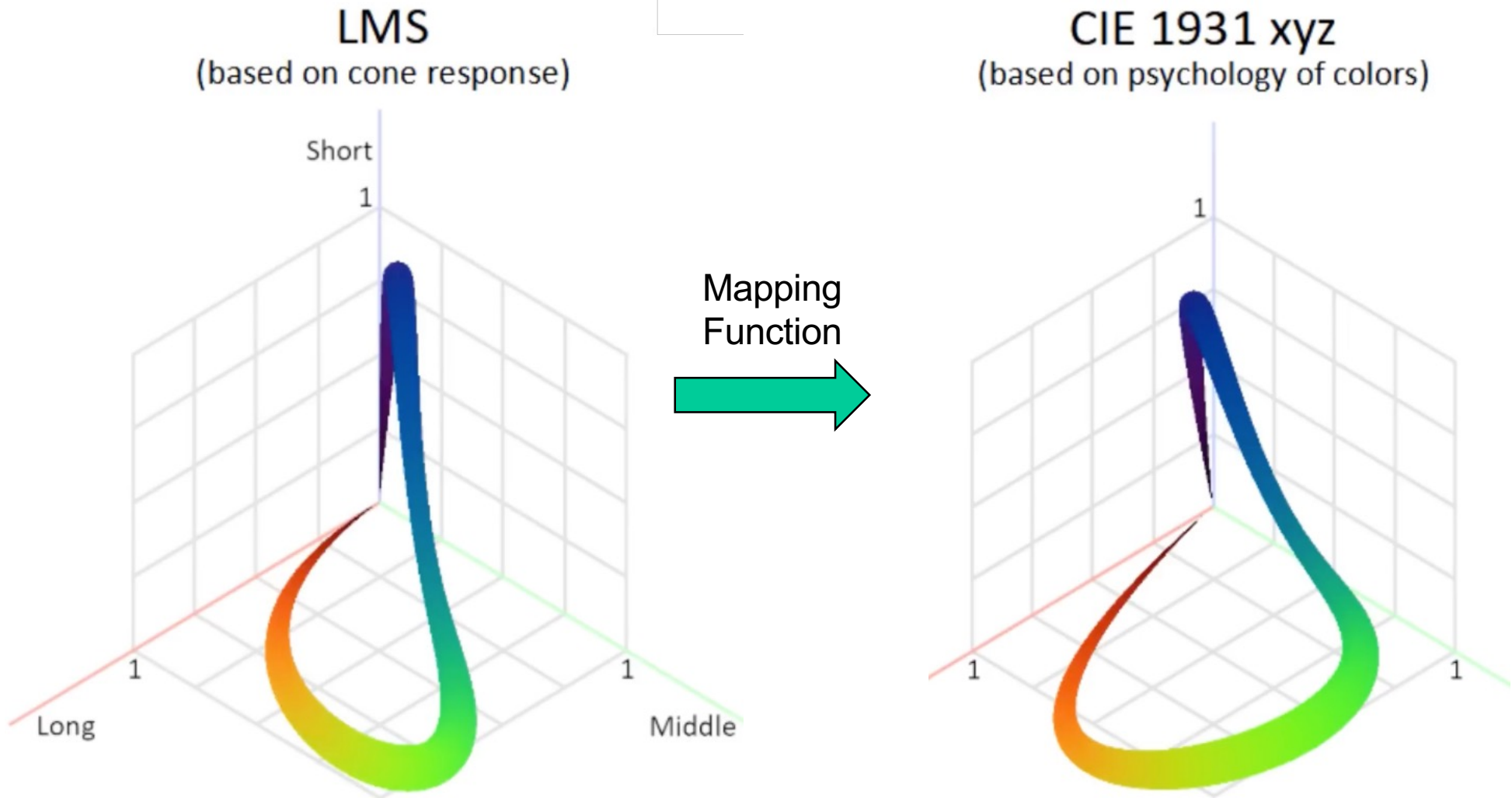
A Complication - Actual Cone Responsivity



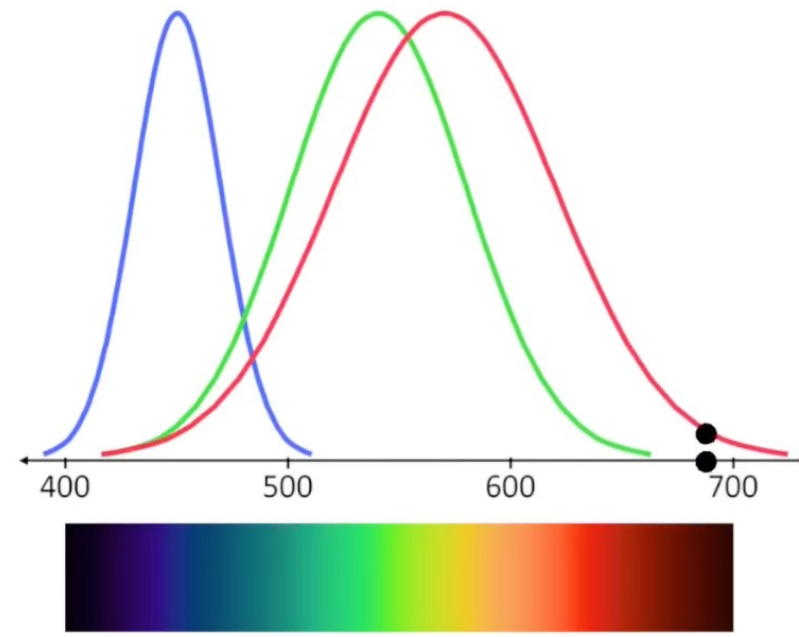
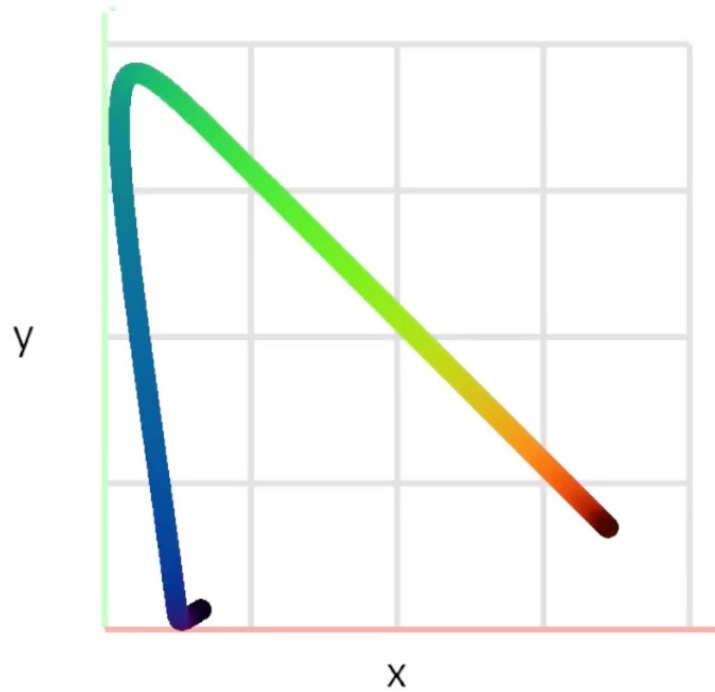
Responsivity



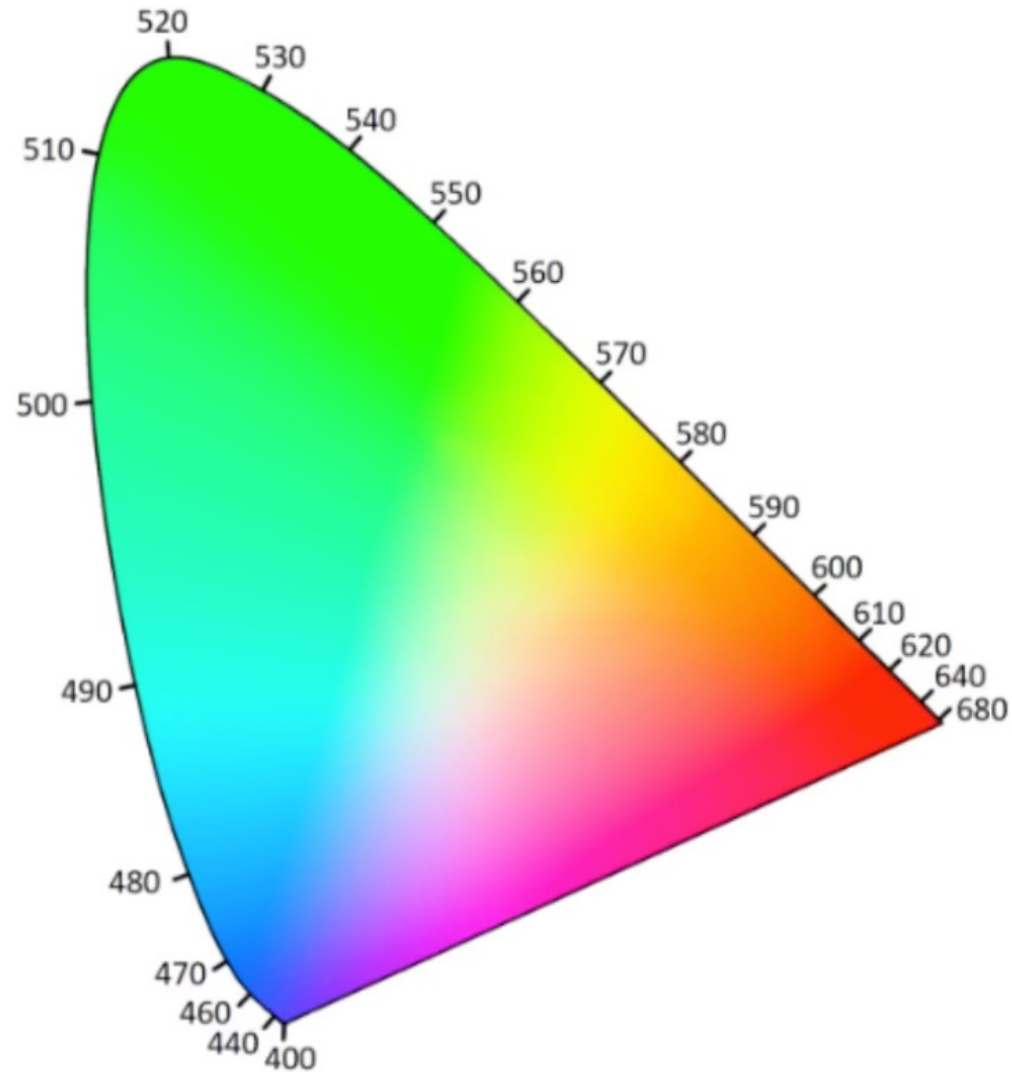
LMS vs CIE 1930 xyz Colour Spaces



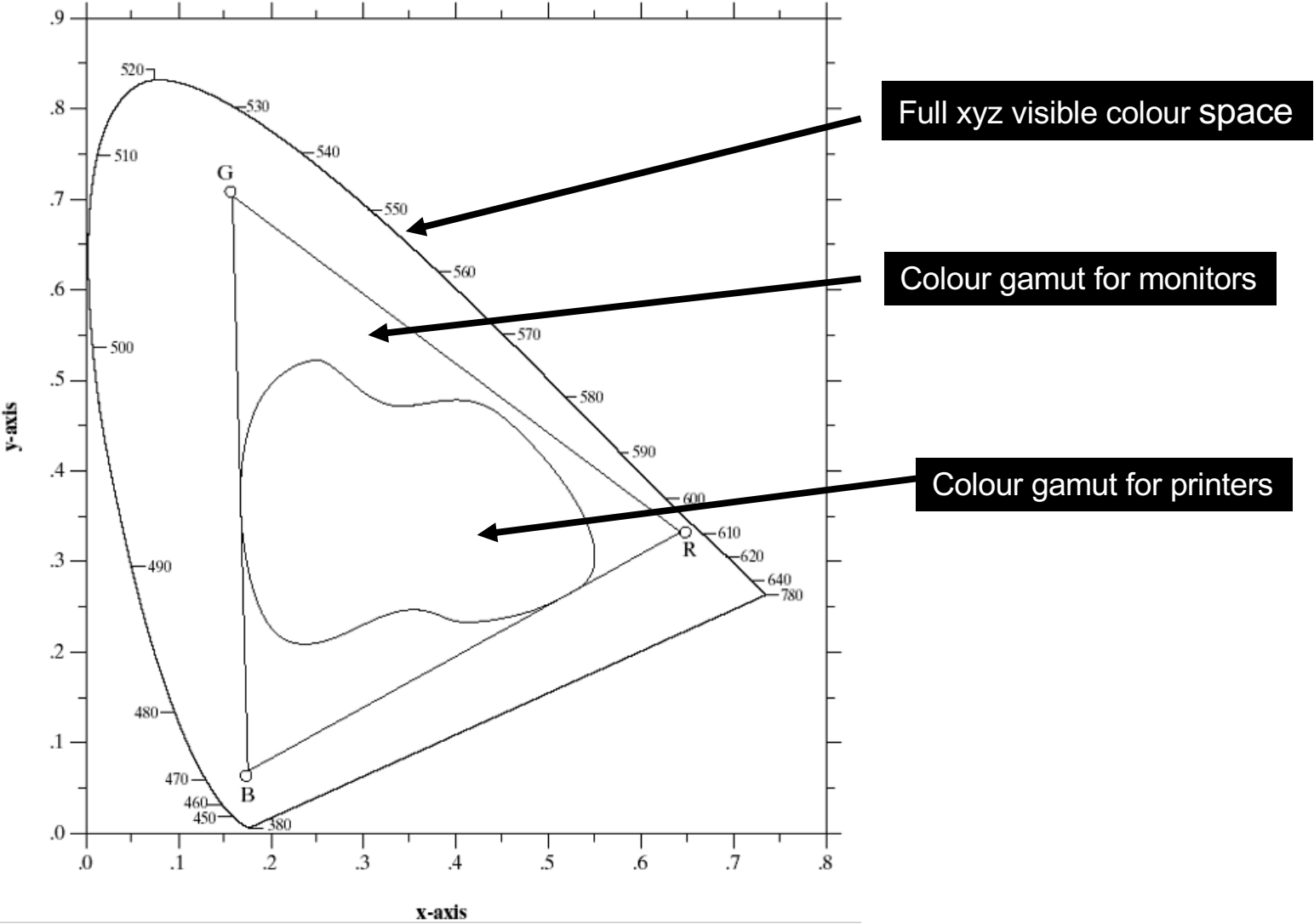
CIE 1931 xy Chromaticity Diagram - monochromatic



CIE 1931 xy Chromaticity Diagram



Restricted colours in printers and monitors

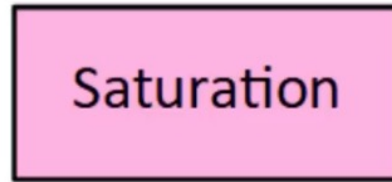
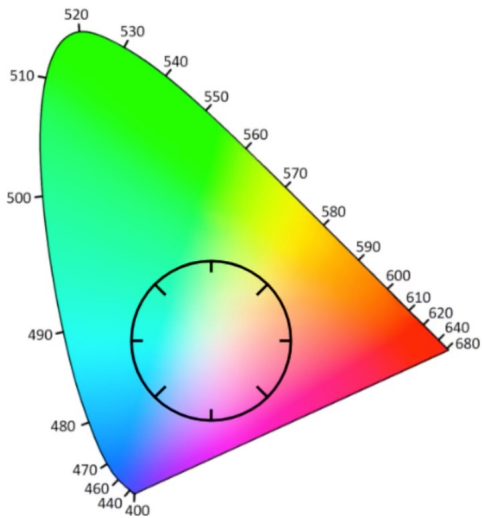


HSV Colour Space



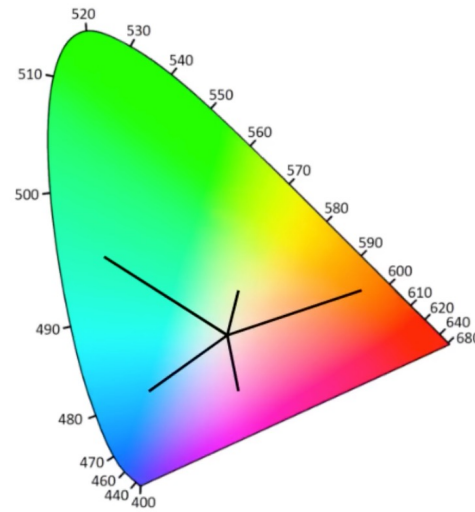
Hue

0 to 360
~ chromaticity
angle



Saturation

0 to 100
~ chromaticity
distance
from center

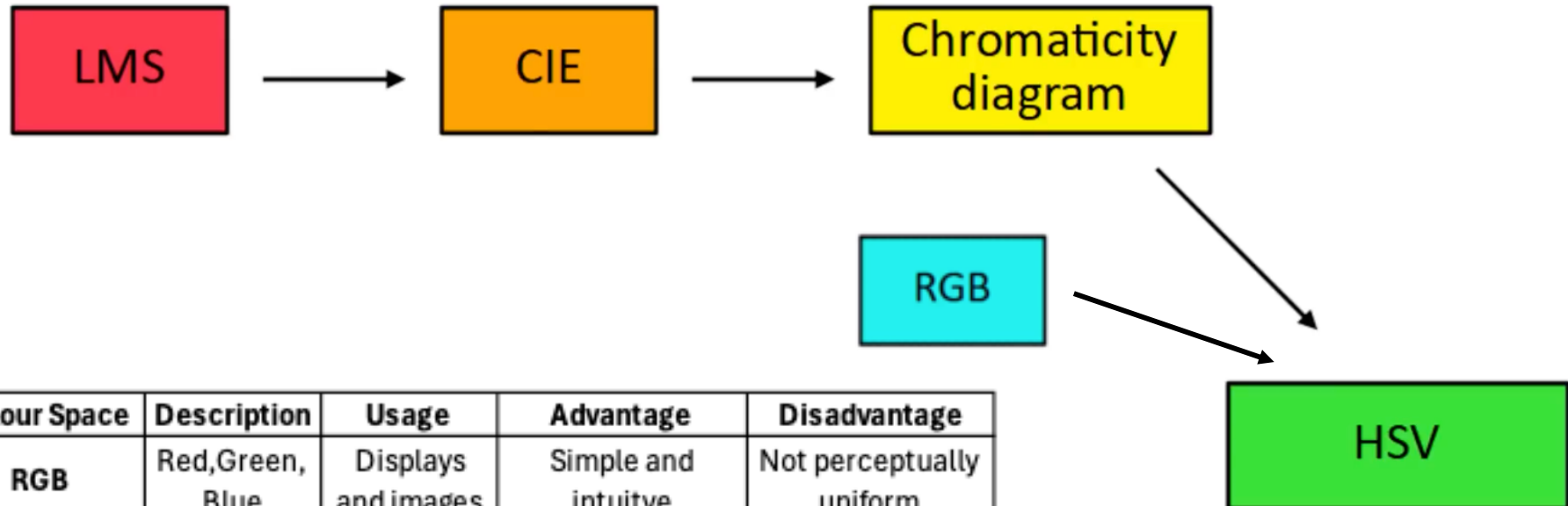


Value

0 to 100
~ luminance



Summary of Colour Spaces



Colour Space	Description	Usage	Advantage	Disadvantage
RGB	Red, Green, Blue	Displays and images	Simple and intuitive	Not perceptually uniform
LMS	Long, Medium, Short	Model human vision	Useful for testing human vision	Complex
xyz	CIE xyz	Colour standard	Device-independent	Not intuitive
HSV	Hue, Saturation, Value	User-friendly colour selection	Useful for colour pickers and image editing	Not device independent